MOUNTAIN-PLAINS CONSORTIUM

MPC 24-563 | C. Cameron, D. Todorut, W. Marshall, N. Coppola, C. Ai, and B.Janson

PEDESTRIAN INFRASTRUCTURE AND ADA COMPLIANCE: LEVERAGING ADVANCES IN SPATIAL TECHNOLOGIES

MOUNTAIN-PLAINS CONSORTIUM REGION 8

A University Transportation Center sponsored by the U.S. Department of Transportation serving the Mountain-Plains Region. Consortium members:

Colorado State University
North Dakota State University
South Dakota State University
University of Colorado Denver
University of Denver
University of Utah
Utah State University
University of Wyoming

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
MPC-678		

4. Title and Subtitle	5. Report Date
Pedestrian Infrastructure and ADA Compliance: Leveraging Advances in Spatial Technologies	September 2024
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Christopher Cameron, PE David Todorut Wesley E. Marshall, PhD, PE Nicholas Coppola, PhD Chengbo Ai, PhD Bruce Janson, PhD	MPC 24-563
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
University of Colorado Denver 1200 Larimer Street Denver, CO 80217	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Mountain-Plains Consortium North Dakota State University PO Box 6050, Fargo, ND 58108	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the US DOT, University Transportation Centers Program

16. Abstract

Despite the ADA's passage in 1990, non-compliant pedestrian infrastructure remains widespread, often due to the lack of comprehensive pedestrian infrastructure data. Traditional methods of measuring compliance are time consuming, prompting the need for more efficient approaches. This research explores the potential and effectiveness of mobile LiDAR technology in assessing ADA compliance of sidewalks and curb ramps in various scenarios.

Part 1 evaluates the capabilities of the iPhone 13 Pro's LiDAR, a low-cost mobile LiDAR technology, against a high-quality Trimble TX8 unit and field measurements. Results suggest that the iPhone's LiDAR is generally effective at detecting minute ADA compliance issues, although with some variability in curb ramp slope measurements.

Part 2 investigates the impact of obstructions on data quality in detecting ADA compliance of sidewalks and curb ramps, such as might be found when pedestrian infrastructure data are collected from the middle of the street instead of from the sidewalk. Findings suggest significant data gaps due to obstructions like vegetation and parked cars when LiDAR data are collected from streets. Despite these challenges, the study highlights the potential of mobile LiDAR, particularly in unobstructed areas, to improve ADA compliance assessments and enhance accessibility for individuals with disabilities.

17. Key Word	18. Distribution Statement
compliance, curbs, geographic information systems, infrastructure, laser radar, legislation, mapping, sidewalks, smartphones	Public distribution

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	175	n/a

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Pedestrian Infrastructure and ADA Compliance: Leveraging Advances in Spatial Technologies

Christopher Cameron, PE
Resident Engineer
Colorado Department of Transportation
2829 W Howard Pl, Denver, CO 80204
christopher.cameron@state.co.us

David Todorut
GIS Technician, Kaart
734 Main Street, Grand Junction, CO 81501
david.todorut@ucdenver.edu

Wesley E. Marshall, PhD, PE
Professor & Associate Chair
University of Colorado Denver
Department of Civil Engineering
1200 Larimer Street Denver, CO 80217
wesley.marshall@ucdenver.edu

Nicholas Coppola, PhD
Adjunct Professor
University of Colorado Denver
Department of Civil Engineering
1200 Larimer Street Denver, CO 80217
nicholas.coppola@ucdenver.edu

Chengbo Ai, PhD
Associate Professor
University of Massachusetts Amherst
Department of Civil & Environmental Engineering
130 Natural Resources Road, Amherst, MA 01003
chengbo.ai@umass.edu

Bruce Janson, PhD
Professor
University of Colorado Denver
Department of Civil Engineering
1200 Larimer Street Denver, CO 80217
bruce.janson@ucdenver.edu

September 2024

Acknowledgments

The authors extend their gratitude to the Mountain Plains Consortium, the U.S. Department of Transportation, the Research and Innovative Technology Administration, and the University of Colorado Denver for funding this research. We also would like to thank Austin Troy and Matt Cross for their assistance with this work.

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

ABSTRACT

Despite the ADA's passage in 1990, non-compliant pedestrian infrastructure remains widespread, often due to the lack of comprehensive pedestrian infrastructure data. Traditional methods of measuring compliance are time consuming, prompting the need for more efficient approaches. This research explores the potential and effectiveness of mobile LiDAR technology in assessing ADA compliance of sidewalks and curb ramps in various scenarios.

Part 1 evaluates the capabilities of the iPhone 13 Pro's LiDAR, a low-cost mobile LiDAR technology, against a high-quality Trimble TX8 unit and field measurements. Results suggest that the iPhone's LiDAR is generally effective at detecting minute ADA compliance issues, although with some variability in curb ramp slope measurements.

Part 2 investigates the impact of obstructions on data quality in detecting ADA compliance of sidewalks and curb ramps, such as might be found when pedestrian infrastructure data are collected from the middle of the street instead of from the sidewalk. Findings suggest significant data gaps due to obstructions like vegetation and parked cars when LiDAR data are collected from streets. Despite these challenges, the study highlights the potential of mobile LiDAR, particularly in unobstructed areas, to improve ADA compliance assessments and enhance accessibility for individuals with disabilities.

TABLE OF CONTENTS

PART 1: IPHONE LIDAR APPLICATIONS UTILIZED FOR PEDESTRIAN INFRASTRUCTURE DATA COLLECTION EFFORTS FOR ADA COMPLIANCE

PART 2: EVALUATING OBSTRUCTIONS & THE ADA COMPLIANCE OF SIDEWALKS USING LIDAR TECHNOLOGY

LIST OF TABLES

LIST OF FIGURES

PART 1: iPHONE LIDAR APPLICATIONS UTILIZED FOR PEDESTRIAN INFRASTRUCTURE DATA COLLECTION EFFORTS FOR ADA COMPLIANCE

1. INTRODUCTION

More than three decades have passed since the enactment of the Americans with Disabilities Act (ADA), yet government entities continue to struggle with ensuring ADA-compliant pedestrian infrastructure. In transportation engineering, sidewalks and curb ramps are crucial for providing access to individuals with physical disabilities. In a 2020 study, Eisenberg et al. revealed that among 401 surveyed government entities, an average of 65% of curb ramps and 48% of sidewalks were inaccessible to pedestrians with disabilities. A significant factor contributing to this non-compliance is the lack of readily available spatial data for pedestrian infrastructure.

Recent advancements in LiDAR technology offer a promising solution for more efficient and accurate data collection. The iPhone 13 Pro's LiDAR capabilities could enable citizens across the United States to gather point cloud data, contributing to a centralized platform aimed at enhancing ADA compliance efforts. Leveraging iPhone LiDAR technology presents an opportunity to create a more equitable transportation system for individuals with disabilities nationwide. Part 1 of this study seeks to answer the question: how effective are iPhone LiDAR applications at identifying ADA compliance issues in pedestrian infrastructure compared with more advanced LiDAR technologies?

Part 1 of this report will provide an in-depth literature review of past pedestrian infrastructure data collection efforts, evaluating their strengths and areas for improvement. We will then use LiDAR technologies from both the Trimble TX8 and iPhone 13 Pro to measure sidewalks and curb ramps for ADA compliance. The performance of the iPhone 13 Pro's LiDAR will be compared with that of the Trimble TX8, a more advanced LiDAR system, as well as with traditional field measurements using tape measures and smart levels. Additionally, the iPhone 13 Pro's ability to stitch together point cloud data into a mosaic will be assessed, exploring the potential for crowdsourcing future ADA data collection efforts.

2. BACKGROUND AND LITERATURE REVIEW

This background and literature review section will begin by examining the Americans with Disabilities Act, with a particular focus on its implications for curb ramps and sidewalks. We will then explore previous methods used for data collection specific to pedestrian infrastructure.

2.1 ADA Law

The Americans with Disabilities Act (ADA) was signed into law on July 26, 1990, by President George H.W. Bush. This civil rights law prohibits discrimination against individuals with disabilities in the United States. Title II of the ADA mandates that state and local governments ensure curb ramps and sidewalks along public roadways are accessible to people with disabilities. The United States Department of Justice initially established the ADA Accessibility Guidelines in 1991, providing instructions on making pedestrian infrastructure accessible. These guidelines were later updated with the 2010 ADA Standards for Accessible Design.

The 2010 ADA Standards for Accessible Design are particularly relevant to this study as they offer detailed guidance for creating ADA-compliant sidewalks and curb ramps. Tables 2.1 and 2.2 list the specific requirements for these features. For curb ramps, some key requirements include a running slope no steeper than 1:12, a level landing at the top that is at least 36 inches long, and curb ramp flares no steeper than 1:10. Although the 2010 ADA Standards refer to “Exterior Accessible Routes” rather than explicitly defining sidewalks, sidewalks fall under this category due to their function and characteristics. For sidewalks to be ADA-compliant, they must, for example, be at least 36 inches wide, have a running slope no steeper than 1:20, and exhibit no more than a ¼-inch vertical change.

Table 2.1 ADA Compliant Curb Ramp Requirements

(Based on 2010 ADA Standards for Accessible Design)

Check Number	Measurement
1	Running Slope < 1:12
2	Cross Slope < 1:48
3	Width ≥ 36 inches
4	Curb Ramp Landing ≥ 36 inches length
5	Curb Ramp Landing ≥ Width of Curb Ramp
6	Curb Ramp Landing < 1:48 slope all directions
7	Curb Ramp Flares < 1:10
8	Counter Slope of Curb and Gutter < 1:20

Table 2.2 ADA Compliant Sidewalk Requirements

(Based on 2010 ADA Standards for Accessbile Design)

Check Number	Measurement
1	Width ≥ 36 inches
2	Passing Space 60"x60" every 200 feet
3	Running Slope < 1:20
4	Cross Slope < 1:48
5	Vertical Height < 1/4 Inch

An interesting finding in the 2010 ADA Standards is that detectable warnings, commonly referred to as truncated domes in the construction industry, are not required on all curb ramps. Detectable warnings serve as a visual and tactile cue for pedestrians with disabilities, indicating the presence of a curb ramp where they can cross the roadway. We had initially believed that detectable warnings were mandatory for all ADA-compliant curb ramps. However, according to the United States Access Board, detectable warnings are only required on curb ramps at transit facilities, such as rail stations and bus stops. Figure 2.1 shows a visual example of detectable warnings on a curb ramp.

Figure 2.1 Curb Ramp Detectable Warning

2.2 ADA Data Collection Efforts

U.S. state and local governments have employed a variety of methods to collect data on curb ramps and sidewalks for ADA compliance. One of the earliest efforts using GPS and digital cameras was conducted by the New Jersey Department of Transportation (NJDOT) in 2006. In this project, GPS units and four digital cameras were mounted on an automobile to inventory sidewalks. This approach was effective in quickly creating a general inventory of pedestrian infrastructure conditions, identifying the presence of sidewalks and curb ramps along county roadways. However, it did not assess specific ADA compliance factors, such as sidewalk widths or the presence of vertical lips.

In 2008, the City of Bellevue, Washington, used an ultra-light inertial profiler (ULIP) mounted on a Segway scooter to measure the slopes and smoothness of sidewalks for ADA compliance. ULIPs are typically used by state DOTs and municipalities for roadway resurfacing projects. While this method effectively captured running slopes, it did not account for minimum lateral distance requirements outlined in ADA standards, such as the required 36-inch sidewalk width. Additionally, the City of Bellevue used a Topcon GMS-2 handheld GPS receiver to assess curb ramp ADA compliance. Although this device effectively integrated data collection into a larger GIS database, it may be considered outdated compared with modern iPhones with LiDAR capabilities. Meanwhile, the Florida Department of Transportation conducted its 2008 ADA compliance inventory of curb ramps and sidewalks using basic tools like smart levels, tape measures, measuring wheels, and clipboards. While these manual methods were necessary in the past, they are now considered time-consuming compared with LiDAR technology, which can capture the same information much more efficiently.

A 2013 study by Frackelton et al. at the Georgia Institute of Technology used the Sidewalk Sentry Android App, mounted on a wheelchair, to conduct a sidewalk inventory in Atlanta, Georgia. The study gathered valuable data, including sidewalk widths, curb ramp presence, and infrastructure obstructions, and integrated these data into a central GIS platform. However, the study did not clarify how effective the data were at identifying specific ADA compliance issues, such as running slopes, cross slopes, and vertical lips. This research aims to address these gaps by using iPhone LiDAR point cloud data to accurately identify ADA compliance issues.

In 2019, Chengbo Ai at the University of Massachusetts led another noteworthy data collection effort using mobile LiDAR mounted on an automobile to measure the ADA compliance of sidewalks and curb ramps (Ai 2019). This method significantly accelerated data collection, capturing spatial information at rates of 7.0 minutes per mile for sidewalks and 2.2 minutes per mile for curb ramps. Additionally, Dr. Ai's research introduced an automated method for assessing ADA compliance of sidewalks and a semi-automated method for curb ramps using LiDAR point cloud data. This study builds on Dr. Ai's work by exploring the potential of iPhones as a medium to crowdsource LiDAR data collection for ADA compliance across the United States.

In 2022, Turkan et al. at Oregon State University developed a method for identifying curb ramps within large LiDAR point cloud datasets. This study effectively utilized mobile LiDAR mounted on an automobile to collect data and introduced ground filtering techniques for faster data analysis. However, the study did not integrate the data into a central GIS platform or comment on the accuracy of the LiDAR data in identifying ADA compliance issues on curb ramps, which could be achieved with iPhone LiDAR applications.

The timeline in Figure 2.2 outlines a few of the key pedestrian infrastructure data collection efforts previously conducted. Table 2.3 summarizes the advantages and disadvantages of these methods. For example, the 2006 NJDOT effort identified general locations of curb ramps, sidewalks, and pedestrian pushbuttons but did not evaluate the number of ADA compliance issues. The 2008 City of Bellevue effort captured running slopes and georeferenced data but did not measure lateral distances or provide a comprehensive ADA assessment. Similarly, the 2008 FDOT effort was accurate in identifying ADA issues but was time consuming and lacked georeferencing. The 2013 Georgia Institute of Technology study identified sidewalk widths, curb ramp presence, and obstructions while being georeferenced but did not provide a comprehensive ADA assessment or address data accuracy. The 2016 University of Massachusetts study identified a comprehensive list of ADA issues and was georeferenced but did not offer crowdsourcing options and was more expensive to deploy compared with iPhone LiDAR data collection. Finally, the 2022 Oregon State University study identified general curb ramp locations and used efficient ground filtering techniques but did not provide a comprehensive ADA overview or comment on data accuracy.

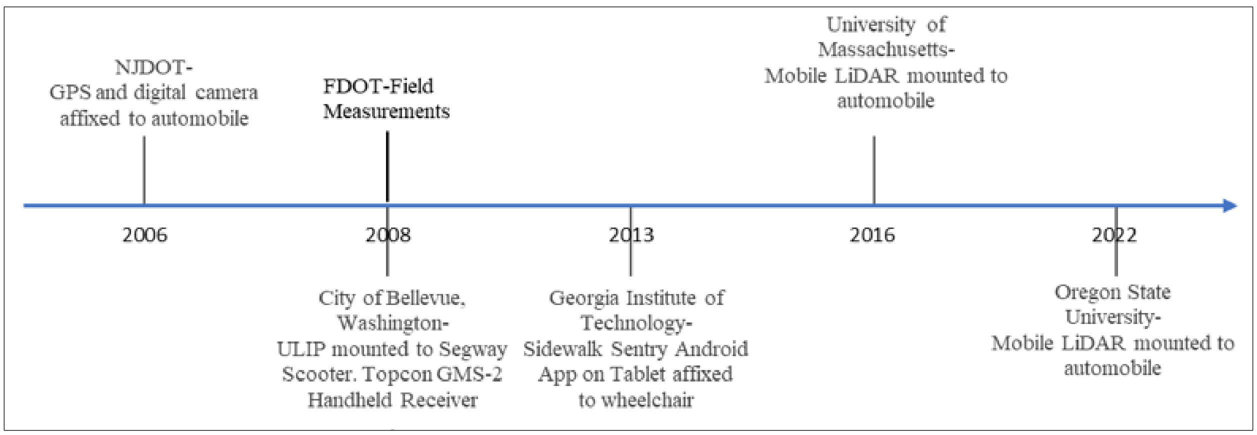


Figure 2.2 Chronological Timeline of ADA Data Collection Methods

Table 2.3 Advantages and Disadvantages of Pedestrian Infrastructure Data Collection Efforts

Year	Entity	Method	Advantages	Disadvantages
2006	NJDOT	GPS and digital camera affixed to automobile	1. Identified general location of curb ramps and sidewalks. 2. Identified general location of pedestrian push buttons.	1. Did not identify number of ADA issues. 2. Did not comment on accuracy of data at identifying ADA issues.
2008	City of Bellevue, Washington	ULIP mounted to Segway Scooter. Topcon GMS-2 Handheld Receiver.	1. Captured Running slopes of sidewalks and curb ramps. 2. Data is geo-referenced.	1. Not effective at lateral distance measurements. 2. Did not provide comprehensive overview of ADA issues at sidewalks and curb ramps.
2008	FDOT	Field Measurements with tape measure, smart level, paper and clipboard	1. Accurate at identifying ADA issues.	1. Time Consuming 2. Requires Transferring the Data to a digital format. 3. Data is not geo-referenced.
2013	Georgia Institute of Technology	Sidewalk Sentry Android App on Tablet affixed to wheelchair	1. Identified sidewalk width, presence of curb ramps, obstructions in pedestrian infrastructure. 2. Data is geo-referenced.	1. Did not provide comprehensive overview ADA issues. 2. Did not comment on the accuracy of the data at identifying ADA issues.
2016	University of Massachusetts	Mobile LiDAR mounted to automobile	1. Identified comprehensive list of ADA issues. 2. Data is geo-referenced.	1. Data did not provide option for crowdsourcing.
2022	Orgeon State University	Mobile LiDAR mounted to automobile	1. Identified general location of curb ramps on larger LiDAR data sets. 2. Ground filtering provided faster data analysis.	1. Did not provide comprehensive overview of ADA issues. 2. Did not comment on the accuracy of the data at identifying ADA issues.

The ADA Act of 1990 serves as the cornerstone to ensure that individuals with physical disabilities can access pedestrian infrastructure. Advancing data collection efforts for pedestrian accessibility requires a thorough evaluation of past methods, which have ranged from manual, labor-intensive techniques involving papers, clipboards, and tape measures, to the use of LiDAR mounted on automobiles. This research aims to build upon these previous approaches by exploring the potential of iPhone LiDAR applications as a viable alternative for data collection.

2.3 Types of Data

Data collection was necessary for this research to determine the effectiveness of LiDAR on the iPhone at measuring pedestrian infrastructure for ADA compliance. To that end, it is important to understand the type of data that were collected. LiDAR works by emitting pulses of light to capture the physical features of the earth's surface, resulting in a point cloud. A point cloud is a dense collection of individual points, each representing an x, y, z coordinate in space, with denser point clouds providing more detailed representations of the objects they depict. These point clouds can be transformed into 3D models for data analysis (Geoslam 2022).

Another advantage of point cloud data is the ability to capture RGB (red-green-blue) colors, which allow the user to distinguish physical features in the dataset. In this research, the RGB color values were particularly effective in identifying the boundaries of curb ramps and sidewalks at the project site. The output file from a LiDAR scan is known as an LAS dataset. According to ESRI's ArcGIS website, an LAS dataset is "an industry-standard binary format for storing airborne LiDAR data." This format offers several benefits, including geo-referencing capabilities, which allow users to locate the dataset on the Earth's surface through a GIS platform. Throughout this report, LAS datasets will often be referred to as point cloud data. Collecting these data is crucial for advancing ADA compliance in pedestrian infrastructure across the United States.

3. SITE SELECTION AND DATA COLLECTION

3.1 Site Selection

In terms of site selection, we attempted to identify block faces and curb ramps in Denver, Colorado, with significant ADA compliance issues to serve as the research site. The City of Denver, with its many older neighborhoods, provided an ideal setting for testing the limits of the iPhone's LiDAR capabilities in measuring ADA compliance. After numerous site visits, the Park Hill neighborhood was selected due to the prevalence of ADA compliance issues observed.

Within Park Hill, the site was further narrowed down to three specific block faces: 28th and Eudora Street, 30th Avenue and Cook Street, and 32nd Avenue and Bruce Randolph Avenue. These block faces were selected because of multiple ADA compliance issues identified on the south block face of 28th Avenue, between Eudora Street and Elm Street. Some of these issues included the absence of a curb cut to the alleyway, sidewalk widths less than 3 feet, and cross slopes steeper than 1:48. Moreover, the research examined three curb ramps at 29th and Elm, 28th and Elm, and 28th and Eudora. We used these three curb ramps and two block faces to conduct a comparative analysis of Trimble TX8 and iPhone LiDAR data for this research project. Finally, field measurements were collected at the following locations to provide additional comparisons to iPhone LiDAR data:

- Secondary curb ramp at 28th Avenue and Eudora Street
- Curb ramp of 29th Avenue and Eudora Street
- Eudora Street block face between 28th Avenue and 29th Avenue
- 29th Avenue block face between Eudora Street and Elm Street

Figures 3.1 and 3.2 show aerial views of the project site location from Google Maps. Figure 3.2 shows an alleyway at the midpoint between Eudora Street and Elm Street that runs from 28th Avenue to 29th Avenue. Figures 3.3 through 3.11 depict the site conditions.

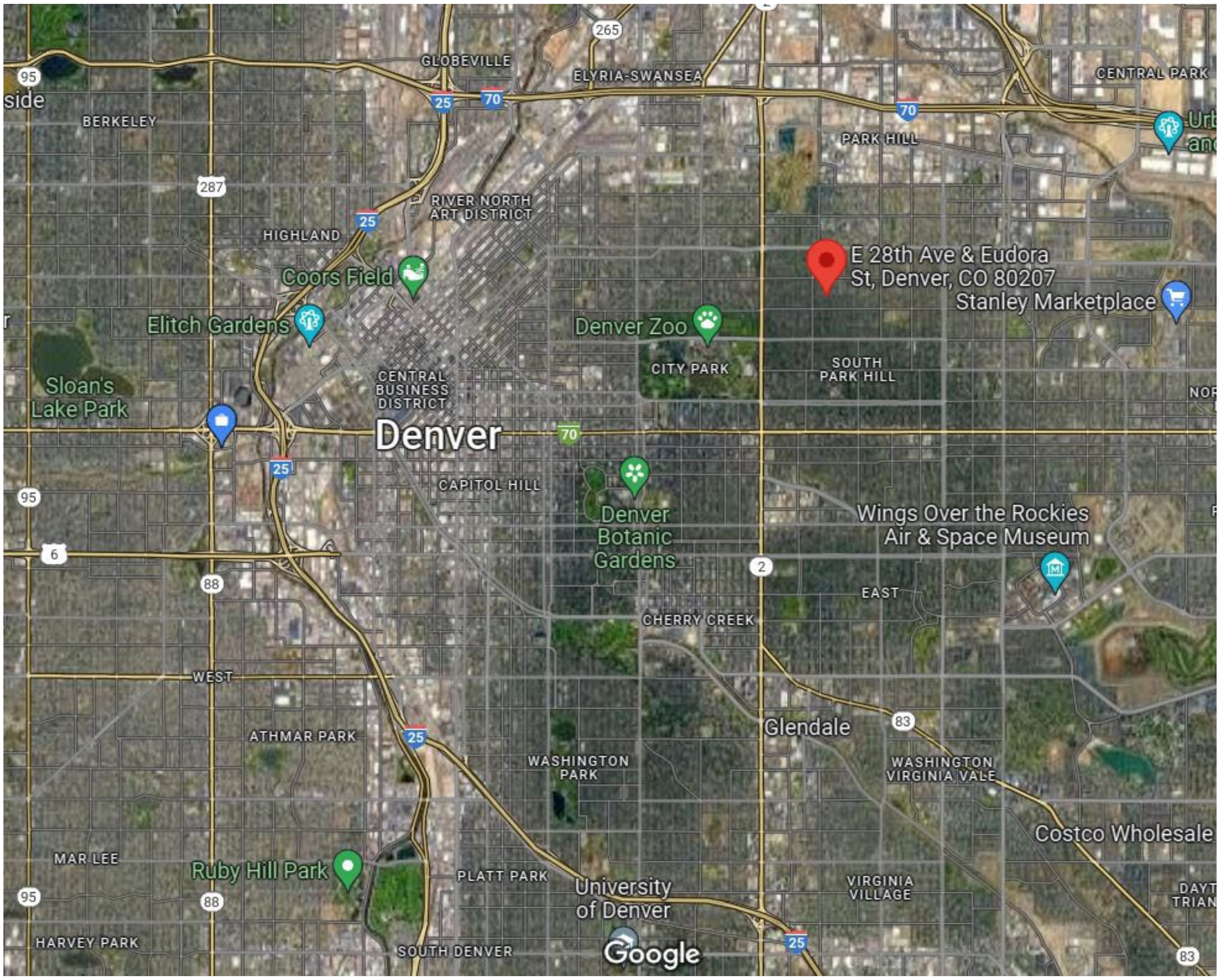


Figure 3.1 Map of Denver with Project Location

Figure 3.2 Plan View of Project Location

Figure 3.3 28th Avenue and Elm Street Curb Ramp

Figure 3.4 28th Avenue and Eudora Street Curb Ramp

Figure 3.5 29th Avenue and Elm Street Curb Ramp

Figure 3.6 29th Avenue and Eudora Street Curb Ramp

Figure 3.7 28th Avenue Alleyway Access

Figure 3.8 28th Avenue Sidewalk

Figure 3.9 29th Avenue Sidewalk

Figure 3.10 Elm Street Sidewalk

Figure 3.11 Eudora Street Sidewalk

3.2 Data Collection

The primary data collection efforts were conducted on June 2, 2022. We collected 3D scans of the sidewalks and curb ramps with the LiDAR CAD app on two iPhone 13 Pros. The LiDAR CAD app allowed us to select GPS reference points while conducting the LiDAR scans. The iPhone uses the World Geodetic System 84, or WGS-84, to collect GPS coordinates on the apps.

We also placed stationary Trimble TX8 LiDAR equipment that collected 3D scans of each block face for the selected block. The first step required us to set three reference points to allow for the LiDAR data to be geo-referenced. The Trimble TX8 LiDAR equipment had capabilities of conducting 3D scans at 100 feet and 1,000 feet. Our project team concluded that a 1,000-foot scan might have less degree of accuracy, so we conducted the scans every 100 feet of each block face. The Trimble TX8 completed each LiDAR scan within a 10-minute time frame. Each time a LiDAR scan was completed, the Trimble TX8 was moved and repositioned to another location and the height of instrument was recorded. We collected 3D scans of the Trimble TX8 LiDAR equipment of the Elm Street block face the week of June 6, 2022.

A second dataset was collected on September 24, 2022, with the 3D scanner app on the iPhone 13 Pro. The 3D scanner app captured point cloud data of the sidewalks and curb ramps at the project site. Using a smart level and tape measure, manual field measurements of the ADA checklists were conducted to identify the following conditions:

- Running slopes
- Cross slopes
- Widths of curb ramps and sidewalks
- ¼" vertical lips
- Counter slopes of curb and gutters

Figures 3.12 through 3.16 depict the equipment used to capture LiDAR data and conduct manual field measurements.

Figure 3.12 Trimble TX7 LiDAR Equipment

Figure 3.13 iPhone 13 Pro LiDAR Equipment

Figure 3.14 Smart Level

Figure 3.15 Tape Measure

Figure 3.16 Measuring Wheel

4. ANALYSIS

The iPhone LiDAR data were gathered using the LiDAR CAD and 3D scanner applications on the iPhone 13 Pro. During the initial site visit on June 2, 2022, the LiDAR CAD application focused primarily on capturing the sidewalk infrastructure, which resulted in incomplete data for the curb ramps. A subsequent site visit on September 24, 2022, used the 3D scanner application to specifically capture the curb ramp infrastructure. Therefore, the point cloud data from the 3D scanner application were selected for comparison with field measurements and Trimble TX8 data, as it provided a more comprehensive capture of the curb ramp features. Additionally, the open-source software "Cloud Compare" was used to analyze the iPhone point cloud data for ADA compliance of the pedestrian infrastructure. Cloud Compare allowed for the measurement of running slopes, cross slopes, and widths of the pedestrian infrastructure using the point-picking tool. Figures 4.1 through 4.7 below provide screenshots of the data analysis performed in Cloud Compare.

Figure 4.1 iPhone Point Cloud Dataset 28th Avenue and Elm Street Curb Ramp

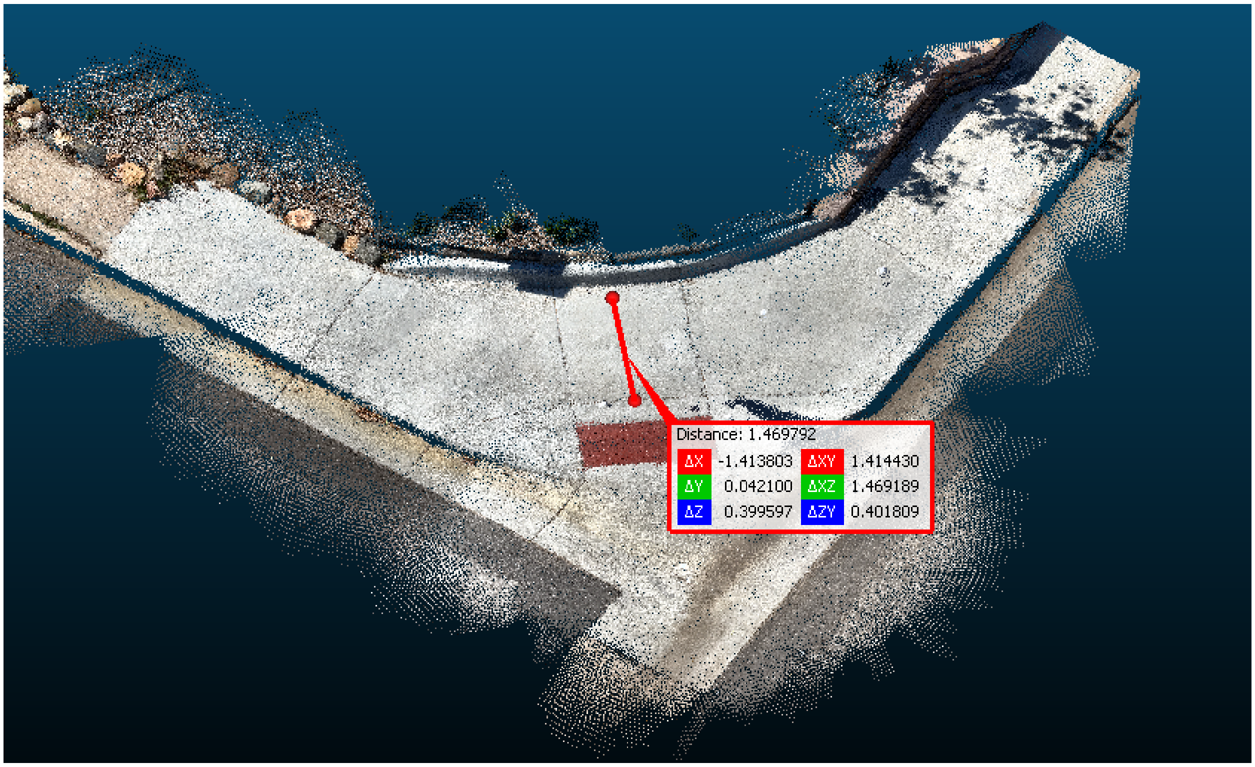


Figure 4.2 iPhone Point Cloud Dataset 29th Avenue and Elm Street Curb Ramp

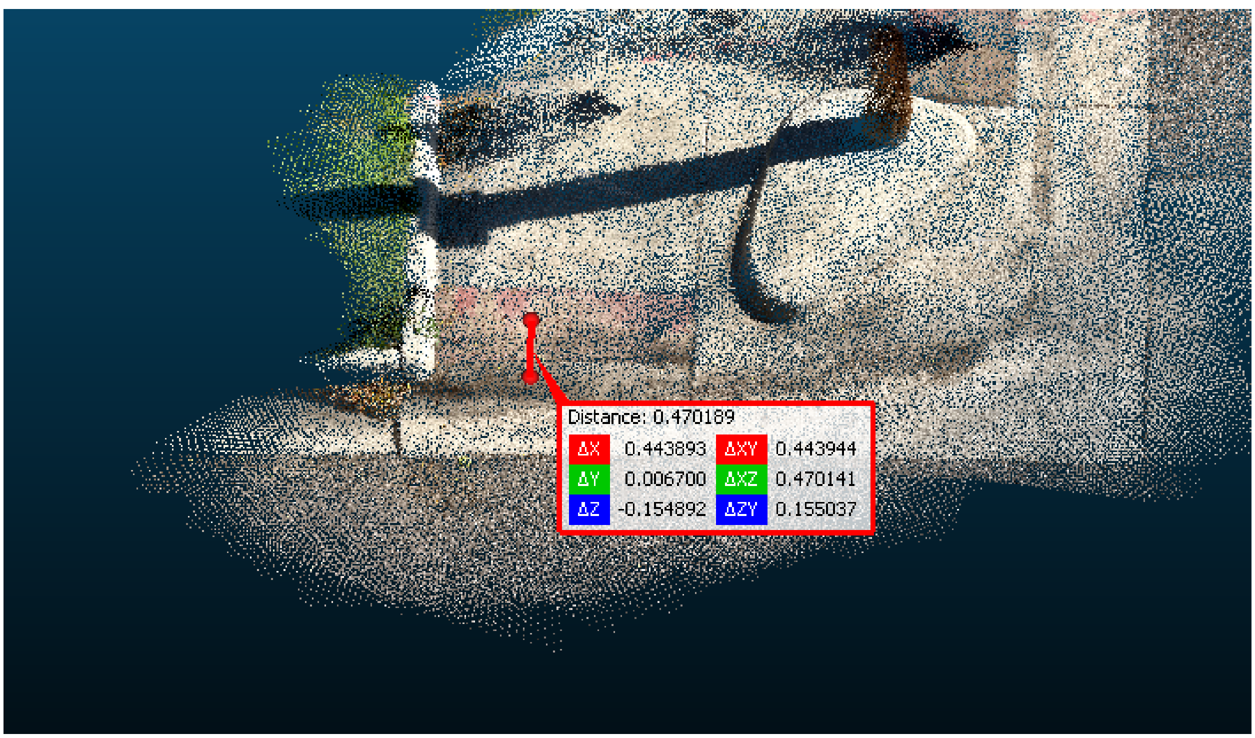


Figure 4.3 iPhone Point Cloud Dataset 28th Avenue and Eudora Street Curb Ramp

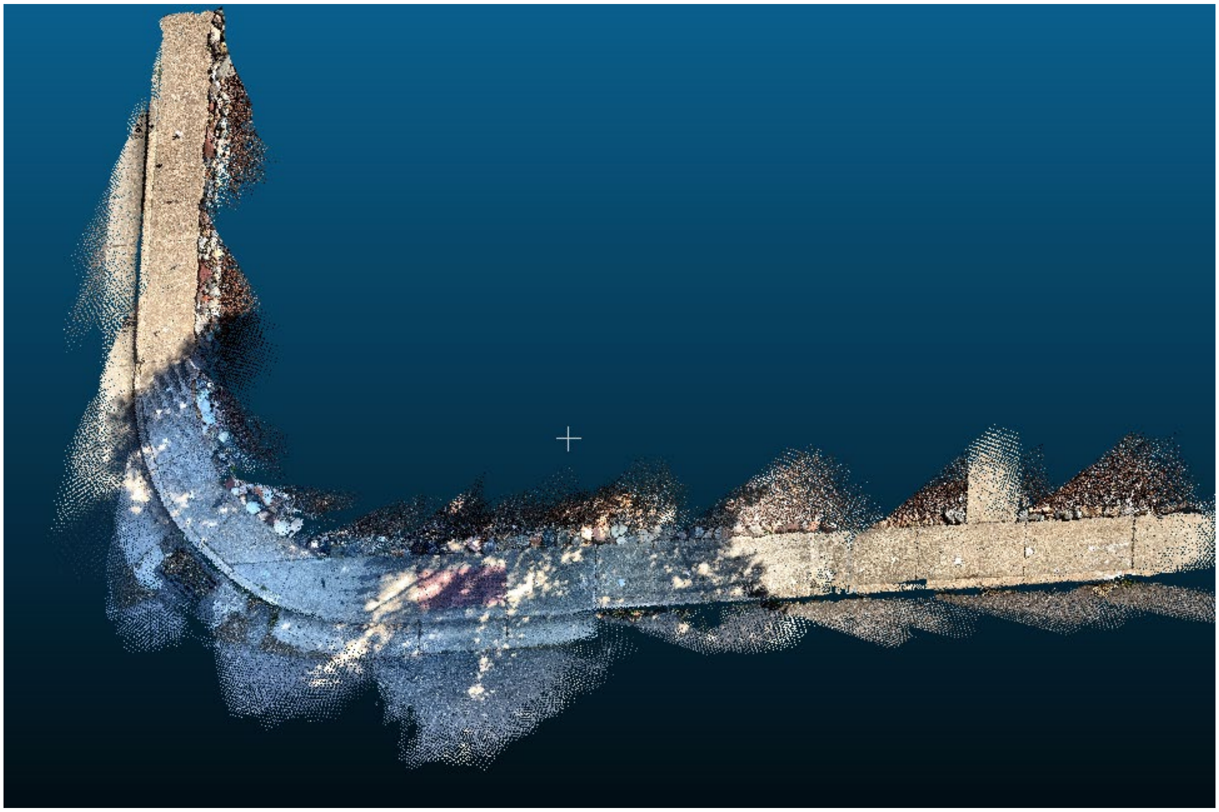


Figure 4.4 iPhone Point Cloud Dataset 29th Avenue and Eudora Street Curb Ramp

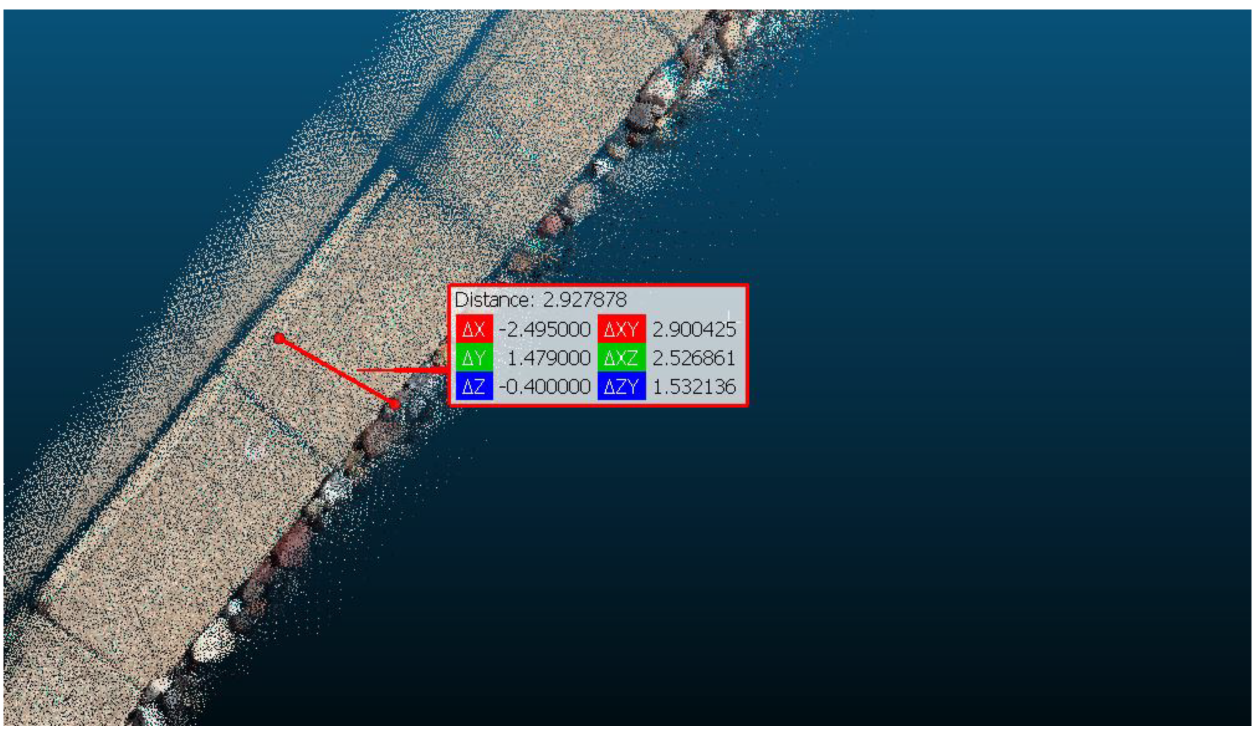


Figure 4.5 iPhone Point Cloud Dataset 29th Avenue Sidewalk

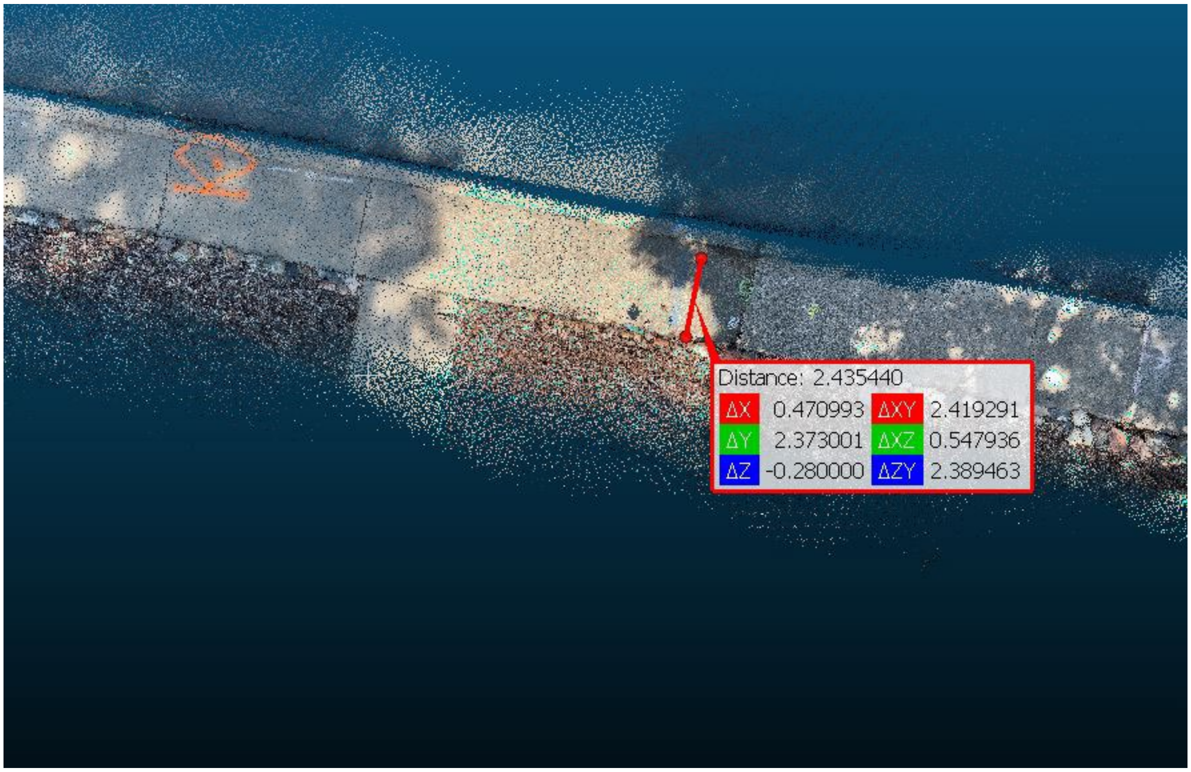


Figure 4.6 iPhone Point Cloud Dataset 29th Elm Street Sidewalk

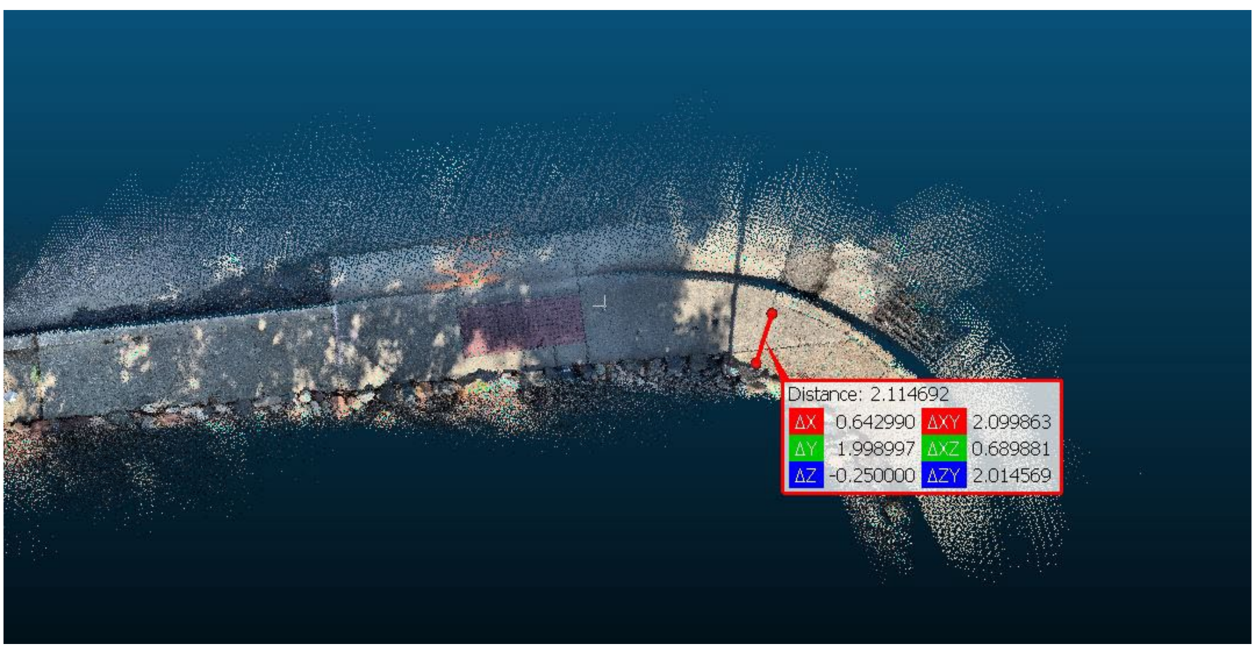


Figure 4.7 Shadows in iPhone Point Cloud Dataset

Another aspect of this research involved identifying ¼-inch lips in the iPhone LiDAR point cloud data. According to the 2010 ADA Standards for Accessible Design, any lips ¼ inch or higher are considered non-compliant with ADA regulations. Through field measurements, the project team initially identified four such lips at the project site.:

1) ¼" lip height located on the Eudora Street block face, 394' north of the corner of Eudora Street and 28th Avenue
2) ¼" lip height located on the Eudora Street block face, 592' north of corner of Eudora Street and 28th Avenue
3) ½" lip height located on the 29th Avenue block face, 44' east of the corner of Eudora Street and 29th Avenue
4) ¾" lip height located on the Elm Street block face, 208' south of the corner of 29th Avenue and Elm Street

All four lips were then identified in the iPhone point cloud data using Cloud Compare software. Figures 4.8 through 4.11 illustrate the lips identified on the project site through field measurements and iPhone point cloud data.

Figure 4.8 iPhone Point Cloud Dataset Lip 1 Eudora Street Sidewalk

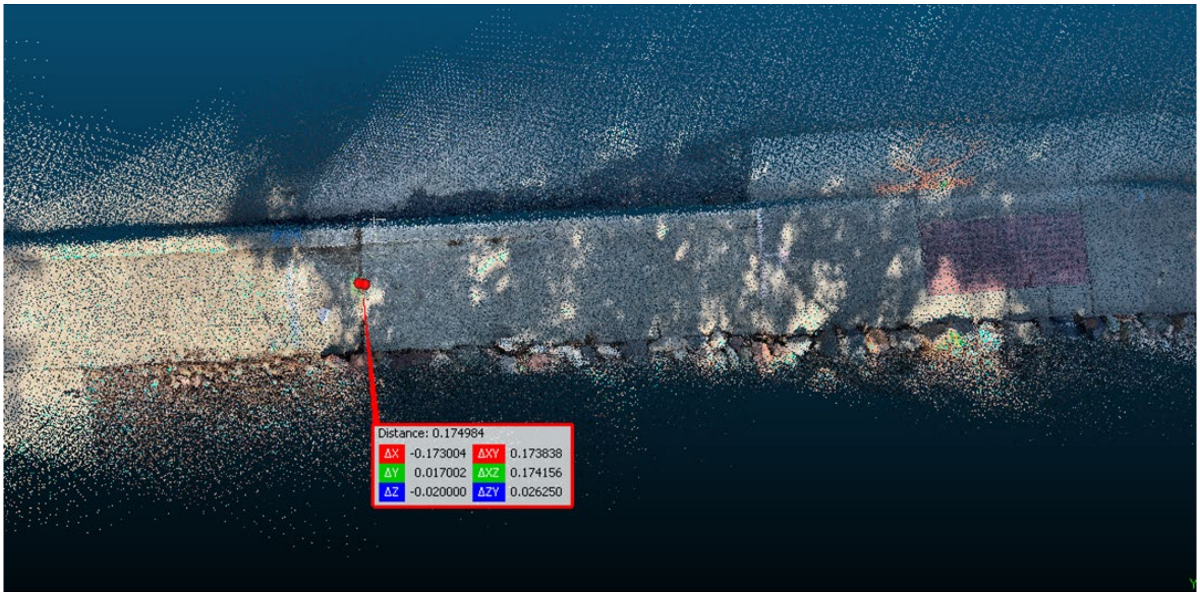


Figure 4.9 iPhone Point Cloud Dataset Lip 2 Eudora Street Sidewalk

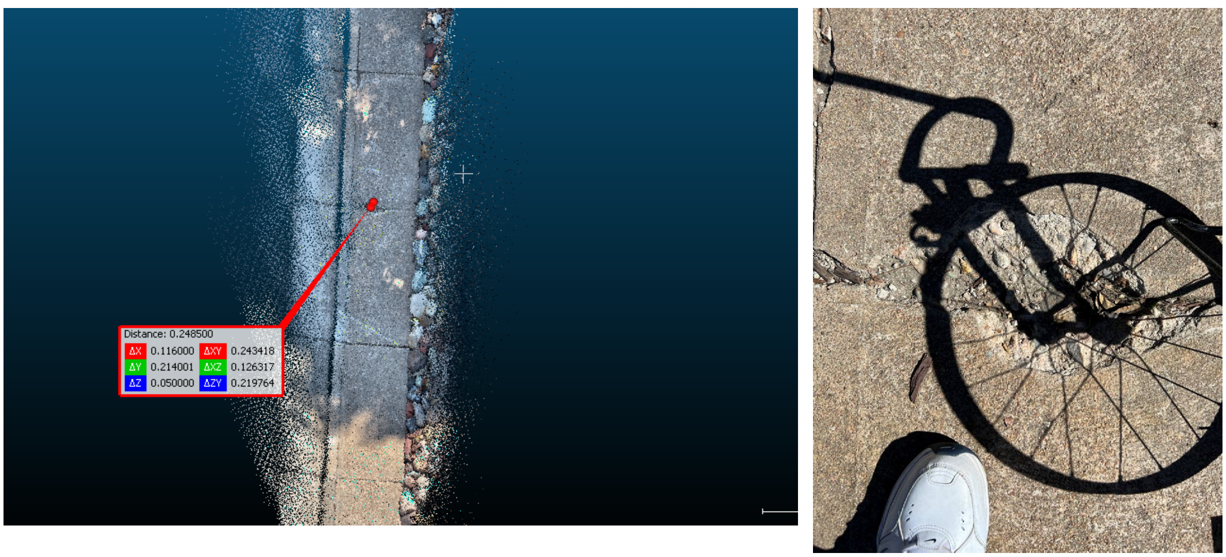


Figure 4.10 iPhone Point Cloud Dataset Lip 3 29th Avenue Sidewalk

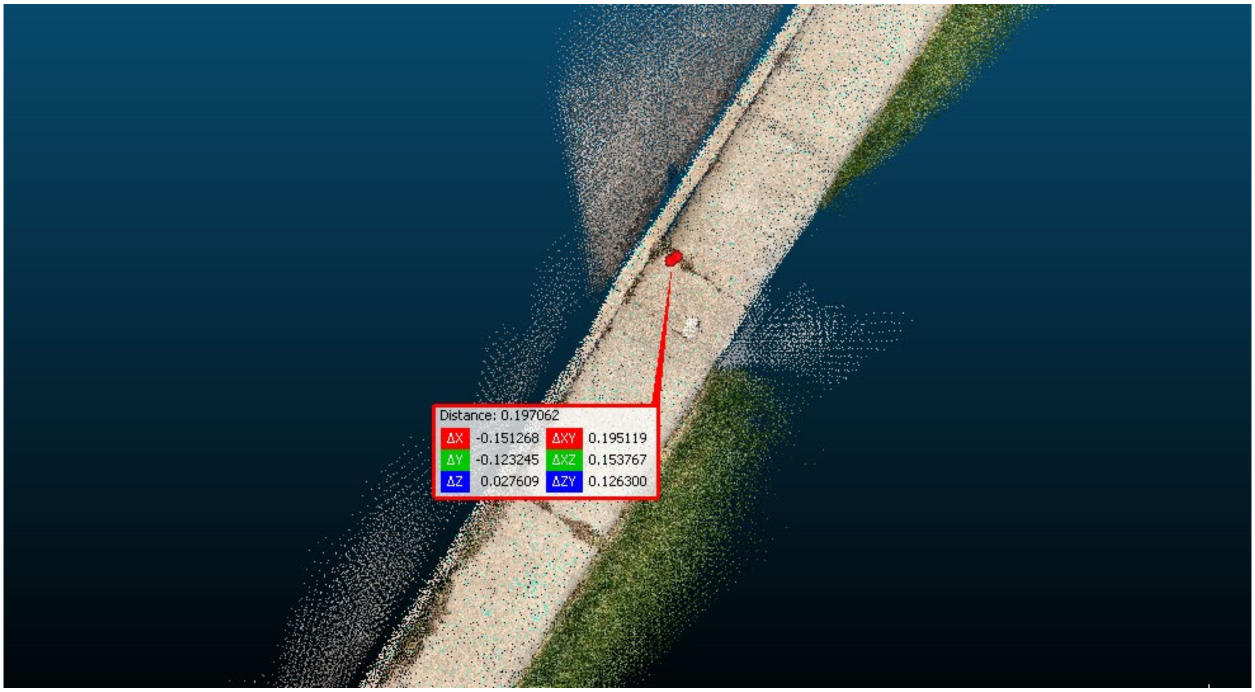


Figure 4.11 iPhone Point Cloud Dataset Lip 4 Elm Street Sidewalk

Analyzing the Trimble TX8 point cloud data presented several challenges, particularly due to the dataset's large size. One Trimble TX8 point cloud dataset had as many as 90 million points and 2 GB of data. When attempting to open this dataset in Cloud Compare, the university's computer lacked the necessary computing power to process it effectively. The dataset was so large that we were unable to pan around the screen or perform any meaningful analysis.

To address this issue, we consulted with Dr. Banaei-Farnoush from the University of Colorado at Denver's Computer Science Department. He confirmed that the university's standard computers did not have the capability to handle such large datasets. He initially suggested using the Alderaan Cluster supercomputer for data analysis. However, upon further investigation, we found that the Alderaan Cluster lacked the necessary graphics component required for the analysis.

We then sought assistance from Dr. Chengbo Ai, who recommended a computer with at least 128 GB of RAM, an Nvidia Titan V GPU, and an i9 CPU for effectively analyzing the Trimble TX8 point cloud datasets. Since the university did not have access to such a computer, Ai developed a web interface specifically for this project to facilitate the analysis of the Trimble TX8 data. This web interface proved to be highly effective in identifying ADA compliance issues. It provided tools for measuring distances and generating vertical profiles to calculate running slopes and cross slopes of the pedestrian infrastructure.

Figures 4.11 through 4.19 provide screenshots of the Trimble TX8 data analysis performed using Dr. Ai's web-based interface.

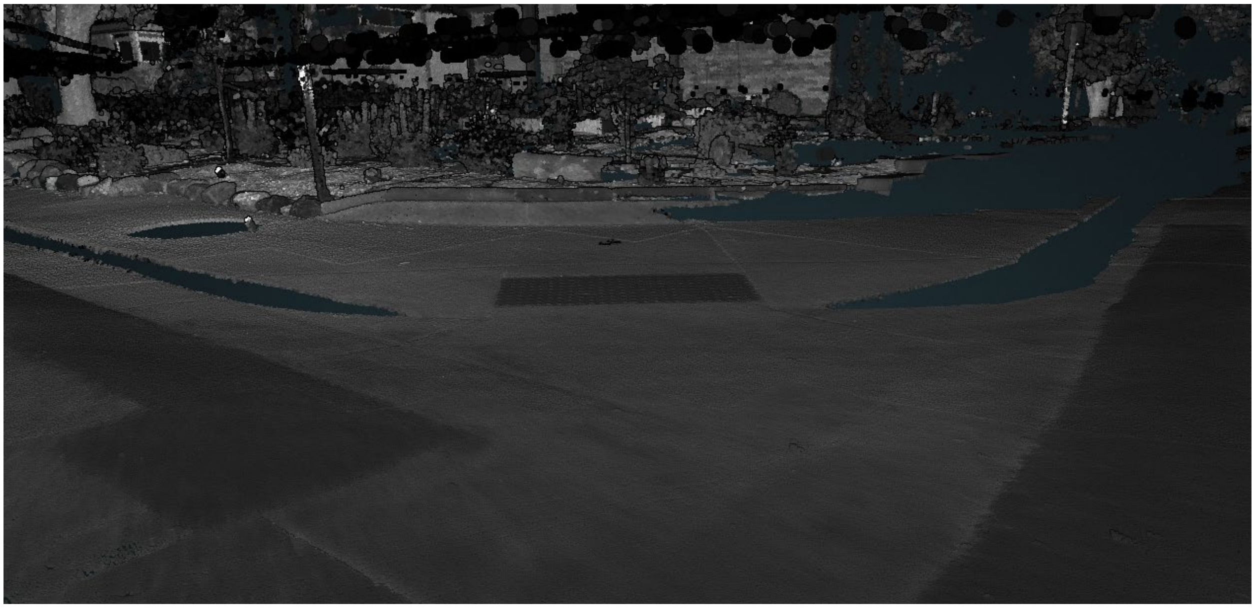


Figure 4.12 Trimble TX8 Point Cloud Dataset 29th Avenue and Elm Street Curb Ramp

Figure 4.13 Trimble TX8 Point Cloud Dataset 28th Avenue and Elm Street Curb Ramp

Figure 4.14 Trimble TX8 Point Cloud Dataset 28th Avenue and Eudora Street South Curb Ramp

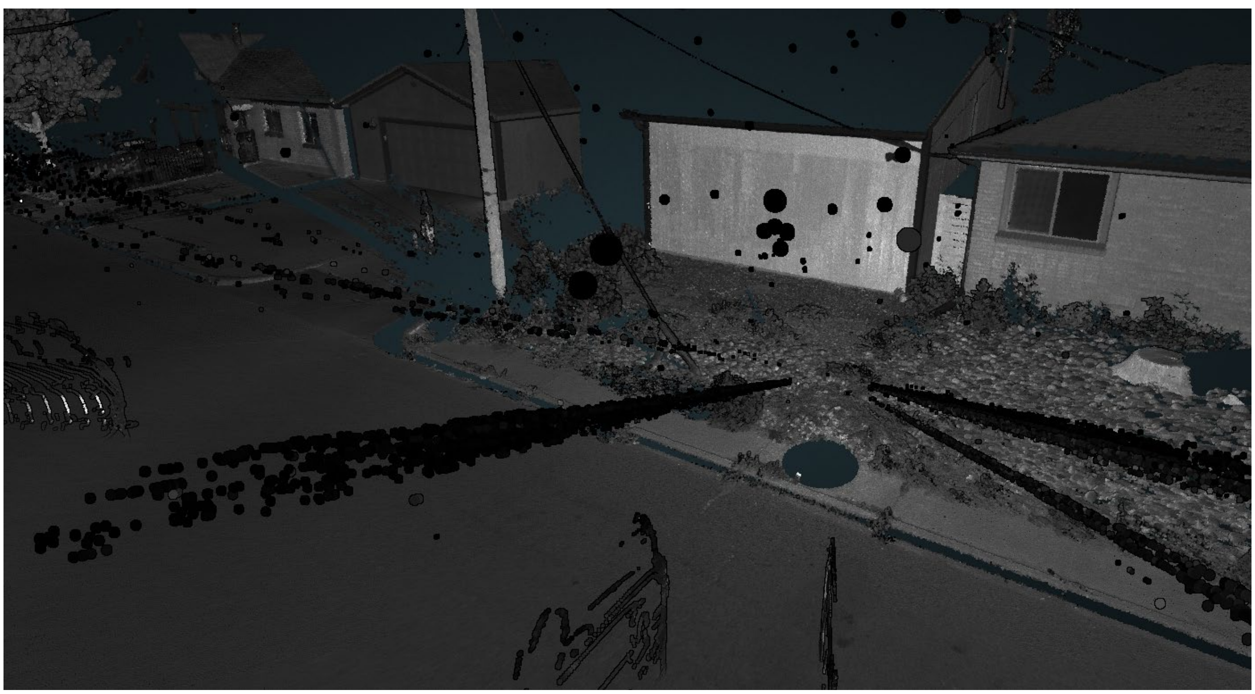


Figure 4.15 Trimble TX8 Point Cloud Dataset 28th Avenue Sidewalk

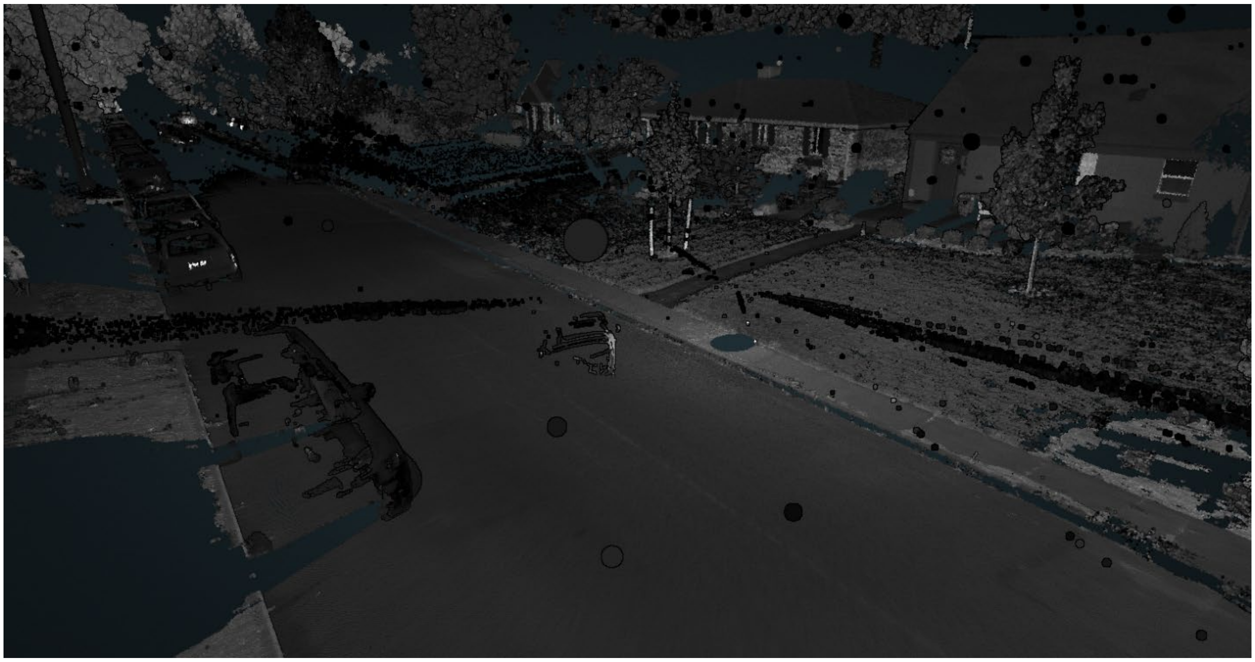


Figure 4.16 Trimble TX8 Point Cloud Dataset Elm Street Sidewalk

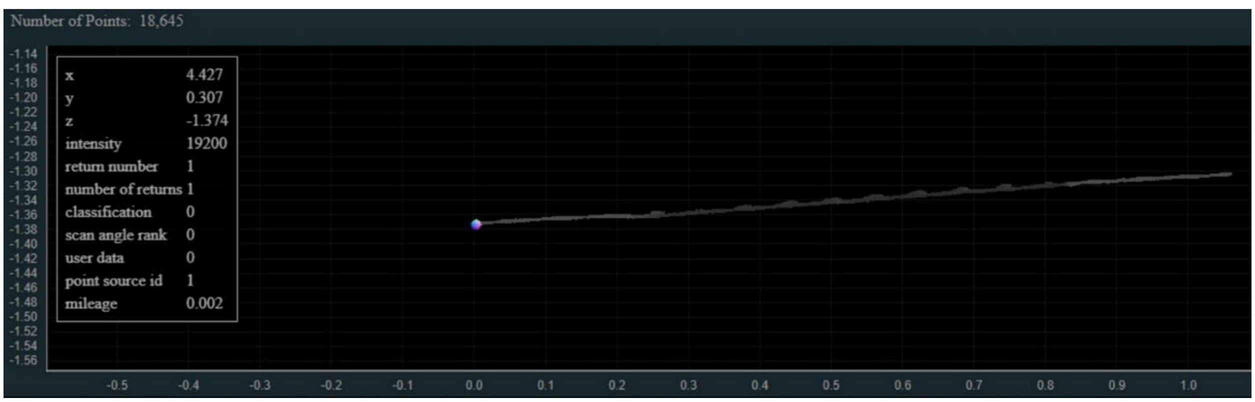


Figure 4.17 Trimble TX8 Point Cloud Dataset 29th Avenue and Elm Street Curb Ramp Running Slope Profile

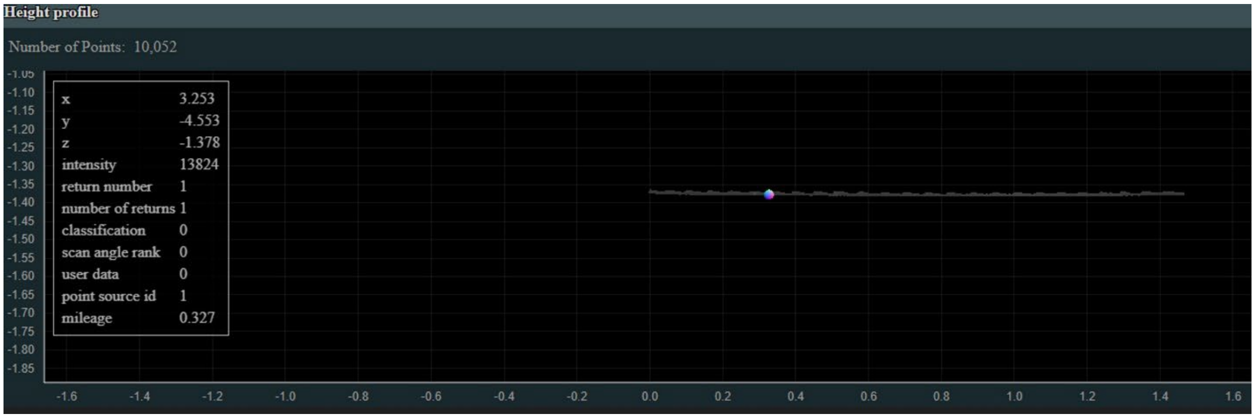


Figure 4.18 Trimble TX8 Point Cloud Dataset 28th Avenue and Eudora Street Curb Ramp Cross Slope Profile

Figure 4.19 Trimble TX8 Point Cloud Dataset 28th Avenue Sidewalk Width

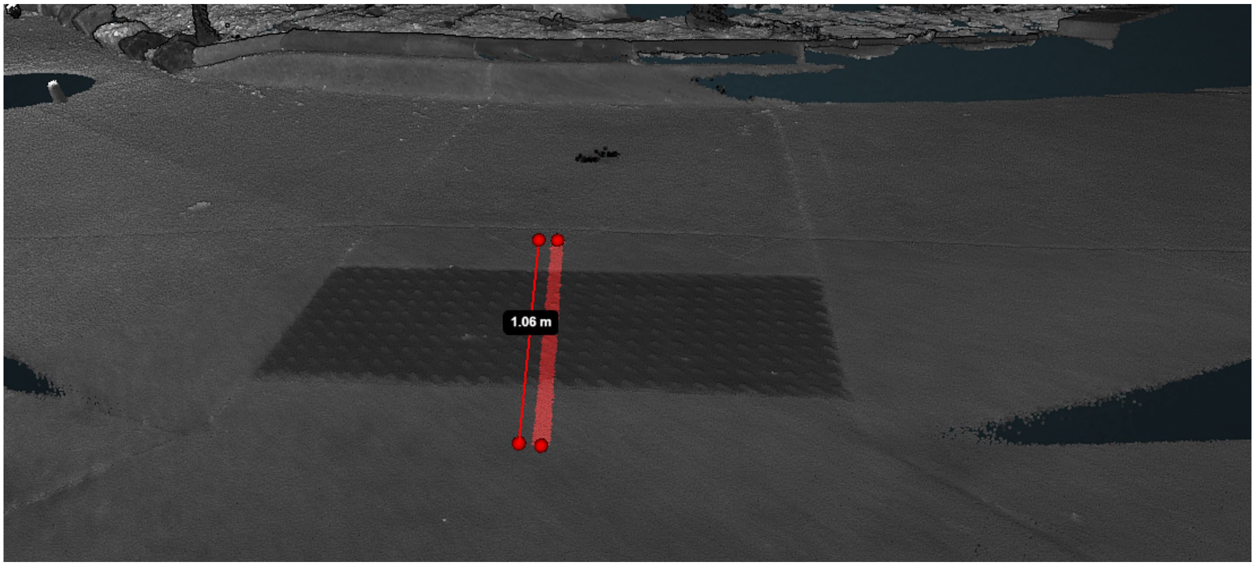


Figure 4.20 Trimble TX8 Point Cloud Dataset 29th and Elm Curb Ramp Running Slope

5. RESULTS

Table 5.1 through 5.10 compare the point cloud data collected using the iPhone with that from the Trimble TX8 and field measurements.

In Table 5.1, which reviews the 28th Avenue and Eudora South curb ramp data, both the Trimble TX8 LiDAR and iPhone LiDAR dataset 1 matched the ADA-related field measurements in eight of eight instances. Three ADA checks were not applicable at this location. However, iPhone LiDAR dataset 2 matched the field measurements in six of eight cases, with two false ADA compliance issues related to inconsistent slope measurements, one for the cross slope and another for the counter slope of the curb and gutter.

Table 5.2, which examines the 29th Avenue and Elm Street curb ramp data, shows that the Trimble TX8 LiDAR data perfectly matched the ADA-related field measurements in all 11 instances. The iPhone dataset 5 matched nine of 11 times, while dataset 6 matched 10 of 11 times. Minor variability was observed between the field measurements and the iPhone LiDAR data, with dataset 5 producing one false cross slope issue and one false running slope issue, and dataset 6 producing one false cross slope issue.

In Table 5.3, for the 28th Avenue and Elm Street curb ramp data, Trimble TX8 dataset 2 and iPhone dataset 4 both matched the ADA-related field measurements in all 11 cases. However, Trimble TX8 dataset 1 and iPhone dataset 4 matched 10 of 11 times, each producing one false ADA compliance issue due to inconsistent cross slope measurements.

Table 5.4 reviews the 29th Avenue and Eudora Street curb ramp data, where iPhone datasets 7 and 8 matched the ADA-related field measurements in seven of eight cases, with three ADA checks not applicable at this location. Both datasets produced one false ADA compliance issue due to inconsistent slope measurements of the curb and gutters.

In Table 5.5, focusing on the 28th Avenue and Eudora Street West curb ramp, iPhone dataset 1 matched all seven ADA-related field measurements, with four ADA checks being inapplicable. iPhone dataset 2 matched six of seven times but produced one false ADA compliance issue due to an inconsistent slope measurement of the curb and gutter.

Tables 5.6 through 5.11 further compare field measurements with Trimble TX8 and iPhone LiDAR data. The iPhone LiDAR datasets successfully detected all ADA compliance issues identified in the field measurements. While the Trimble TX8 LiDAR datasets showed some variability, this could be because the field measurements covered entire block faces, whereas the Trimble TX8 data only captured segments. As a result, not every segment had the same number of ADA compliance issues.

Overall, the iPhone LiDAR data proved to be highly accurate in detecting ADA compliance issues on sidewalks within the scope of this research. The iPhone LiDAR data matched ADA-related field conditions in six of six cases. Additionally, the iPhone LiDAR data successfully identified vertical lips on sidewalks, ranging from ¼ to ¾ inches in all four scenarios. While there was some variability in slope measurements between the iPhone LiDAR data and field conditions, the iPhone LiDAR data generally matched the majority of ADA-related field conditions for curb ramps. Based on this research, iPhone LiDAR data can be considered an effective tool for measuring sidewalks and curb ramps for ADA compliance.

Table 5.1 Comparison of Field Data with Trimble and IPhone Data at 28th Avenue and Eudora Street Curb Ramp using CU Denver ADA Curb Ramp Checklist

Check Number	Field	Trimble	iPhone	iPhone
1 Running Slope	Yes	Yes	Yes	Yes
2 Cross Slope	Yes	Yes	Yes	No
3 Width	Yes	Yes	Yes	Yes
4 Landing	No	No	No	No
5 Flares	Yes	Yes	Yes	Yes
6 Counter Slope	Yes	Yes	Yes	No
7 Curb	N/A	N/A	N/A	N/A
8 Clear Space	N/A	N/A	N/A	N/A
9 Curb Ramp	Yes	Yes	Yes	Yes
10 Outside Traffic	Yes	Yes	Yes	Yes
11 Drainage	N/A	N/A	N/A	N/A

Table 5.2 Comparison of Field Data with Trimble and IPhone Data at 29th Avenue and Elm Street Curb Ramp using CU Denver ADA Curb Ramp Checklist

Check Number	Field	Trimble	Trimble	iPhone	iPhone
1 Running Slope	Yes	Yes	Yes	No	Yes
2 Cross Slope	Yes	Yes	Yes	Yes	Yes
3 Width	Yes	Yes	Yes	Yes	Yes
4 Landing	Yes	Yes	Yes	No	No
5 Flares	Yes	Yes	Yes	Yes	Yes
6 Counter Slope	Yes	Yes	Yes	Yes	Yes
7 Curb	No	No	No	No	No
8 Clear Space	No	No	No	No	No
9 Curb Ramp	Yes	Yes	Yes	Yes	Yes
10 Outside Traffic	Yes	Yes	Yes	Yes	Yes
11 Drainage	Yes	Yes	Yes	Yes	Yes

Table 5.3 Comparison of Field Data with Trimble and IPhone Data at 28th Avenue and Elm Street Curb Ramp using CU Denver ADA Curb Ramp Checklist

Check Number	Field	Trimble	Trimble	iPhone	iPhone
1 Running Slope	Yes	Yes	Yes	Yes	Yes
2 Cross Slope	Yes	Yes	Yes	Yes	Yes
3 Width	Yes	Yes	Yes	Yes	Yes
4 Landing	Yes	No	Yes	No	Yes
5 Flares	Yes	Yes	Yes	Yes	Yes
6 Counter Slope	Yes	Yes	Yes	Yes	Yes
7 Curb	No	No	No	No	No
8 Clear Space	No	No	No	No	No
9 Curb Ramp	Yes	Yes	Yes	Yes	Yes
10 Outside Traffic	Yes	Yes	Yes	Yes	Yes
11 Drainage	Yes	Yes	Yes	Yes	Yes

Table 5.4 Comparison of Field Data with Trimble and IPhone Data at 29th Avenue and Eudora Street Curb Ramp using CU Denver ADA Curb Ramp Checklist

Check Number	Field	iPhone	iPhone
1 Running Slope	No	No	No
2 Cross Slope	Yes	Yes	Yes
3 Width	Yes	Yes	Yes
4 Landing	No	No	No
5 Flares	Yes	Yes	Yes
6 Counter Slope	Yes	No	No
7 Curb	N/A	N/A	N/A
8 Clear Space	N/A	N/A	N/A
9 Curb Ramp	Yes	Yes	Yes
10 Outside Traffic	Yes	Yes	Yes
11 Drainage	N/A	N/A	N/A

Table 5.5 Comparison of Field Data with Trimble and IPhone Data at 28th Avenue and Eudora West Curb Ramp using CU Denver ADA Curb Ramp Checklist

Check Number	Field	iPhone	iPhone
1 Running Slope	Yes	Yes	Yes
2 Cross Slope	Yes	Yes	Yes
3 Width	Yes	Yes	Yes
4 Landing	No	No	No
5 Flares	N/A	N/A	N/A
6 Counter Slope	Yes	Yes	No
7 Curb	N/A	N/A	N/A
8 Clear Space	N/A	N/A	N/A
9 Curb Ramp	Yes	Yes	Yes
10 Outside Traffic	Yes	Yes	Yes
11 Drainage	N/A	N/A	N/A

Table 5.6 Comparison of Field Data with Trimble Data for 28th Avenue Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	Trimble	Trimble	Trimble	Trimble	Trimble
Check 1 Width	No	No	No	No	No	No
Check 2 Passing Space	Yes	Yes	Yes	Yes	Yes	Yes
Check 3 Grate Opening	N/A	N/A	N/A	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No	No	No	No
Check 7 Vertical Change	No	No	Yes	No	No	No
Check 8 Stable Route	Yes	Yes	Yes	Yes	Yes	Yes

*Trimble TX8 LiDAR Scans only covered segments of 28th Ave. Variability could be expected when comparing to entire block face of field measurements.

Table 5.7 Comparison of Field Data with iPhone Data for 28th Avenue Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	iPhone	iPhone
Check 1 Width	No	No	No
Check 2 Passing Space	Yes	Yes	Yes
Check 3 Grate Opening	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No
Check 7 Vertical Change	No	No	No
Check 8 Stable Route	Yes	Yes	Yes

Table 5.8 Comparison of Field Data with Trimble Data for Elm Street Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble	Trimble
Check 1 Width	No	No	No	No	No	No	No	No	No	No	No	No	No
Check 2 Passing Space	No	No	No	No	No	No	No	No	No	No	No	No	No
Check 3 Grate Opening	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No	No	No	No	No	No	No	No	No	No	No
Check 7 Vertical Change	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes
Check 8 Stable Route	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*Trimble TX8 LiDAR Scans only covered segments of Elm St. Variability could be expected when comparing to entire block face of field measure

Table 5.9 Comparison of Field Data with iPhone Data for Elm Street Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	iPhone	iPhone
Check 1 Width	No	No	No
Check 2 Passing Space	No	No	No
Check 3 Grate Opening	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No
Check 7 Vertical Change	No	No	No
Check 8 Stable Route	Yes	Yes	Yes

Table 5.10 Comparison of Field Data with Trimble Data for 29th Avenue Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	iPhone	iPhone
Check 1 Width	No	No	No
Check 2 Passing Space	Yes	Yes	Yes
Check 3 Grate Opening	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No
Check 7 Vertical Change	No	No	No
Check 8 Stable Route	Yes	Yes	Yes

Table 5.11 Comparison of Field Data with iPhone Data for Eudora Street Sidewalk using CU Denver ADA Sidewalk Checklist

	Field	iPhone	iPhone
Check 1 Width	No	No	No
Check 2 Passing Space	No	No	No
Check 3 Grate Opening	N/A	N/A	N/A
Check 4 Grate Direction	N/A	N/A	N/A
Check 5 Running Slope	Yes	Yes	Yes
Check 6 Cross Slope	No	No	No
Check 7 Vertical Change	No	No	No
Check 8 Stable Route	No	No	No

6. DISCUSSION

This discussion section is divided into two parts: the first addresses the hardware and software challenges encountered during data analysis for this research, and the second offers recommendations for future research utilizing iPhone LiDAR applications.

One limitation discovered with the LiDAR CAD app was its inability to capture an entire city block in a single 3D scan. Despite three attempts, the app crashed each time before the scan could be completed, likely due to the size of the point cloud data. However, the LiDAR CAD app successfully completed 3D scans of individual block faces, with lengths ranging from 300 to 630 feet at the test site.

Several issues arose when analyzing the LiDAR data from the LiDAR CAD app. It is important to note that the LiDAR CAD app initially outputs LiDAR scans as DWG files, although it can export these DWG files to other formats such as JPEG, PDF, PTS, PLY, LAS, USDZ, OBJ, and STL. The limitation of having only DWG files as the original output format created challenges in data analysis. The DWG files included GPS coordinates from each LiDAR scan, which were analyzed using AutoCAD Civil 3D. However, when importing the DWG files into AutoCAD Civil 3D, the data required manual "stitching" to form a complete city block of 28th Avenue, 29th Avenue, Eudora Street, and Elm Street. This process involved creating a "dummy" layer in AutoCAD Civil 3D, manually inputting the GPS coordinates from each scan, and snapping the DWG files together to assemble the full city block.

In contrast, LiDAR scans exported as LAS files are automatically stitched together, eliminating the need for manual data entry and processing to geo-reference each file. When the LiDAR CAD app was used to export DWG files to LAS files for further analysis in ArcGIS Pro, it was discovered that the GPS coordinates disappeared, and the LAS files were not geo-referenced. As a result, the point cloud data appeared in the middle of the Atlantic Ocean, as shown in Figure 6.1. The project team reached out to Svetlana Sandalova, who created the LiDAR CAD app, for assistance. She confirmed via email that exported LAS files from the app are not geo-referenced, acknowledging this as a limitation of the current version. She also mentioned that she is exploring the possibility of adding geo-referenced information to LAS files in future updates to the LiDAR CAD application.

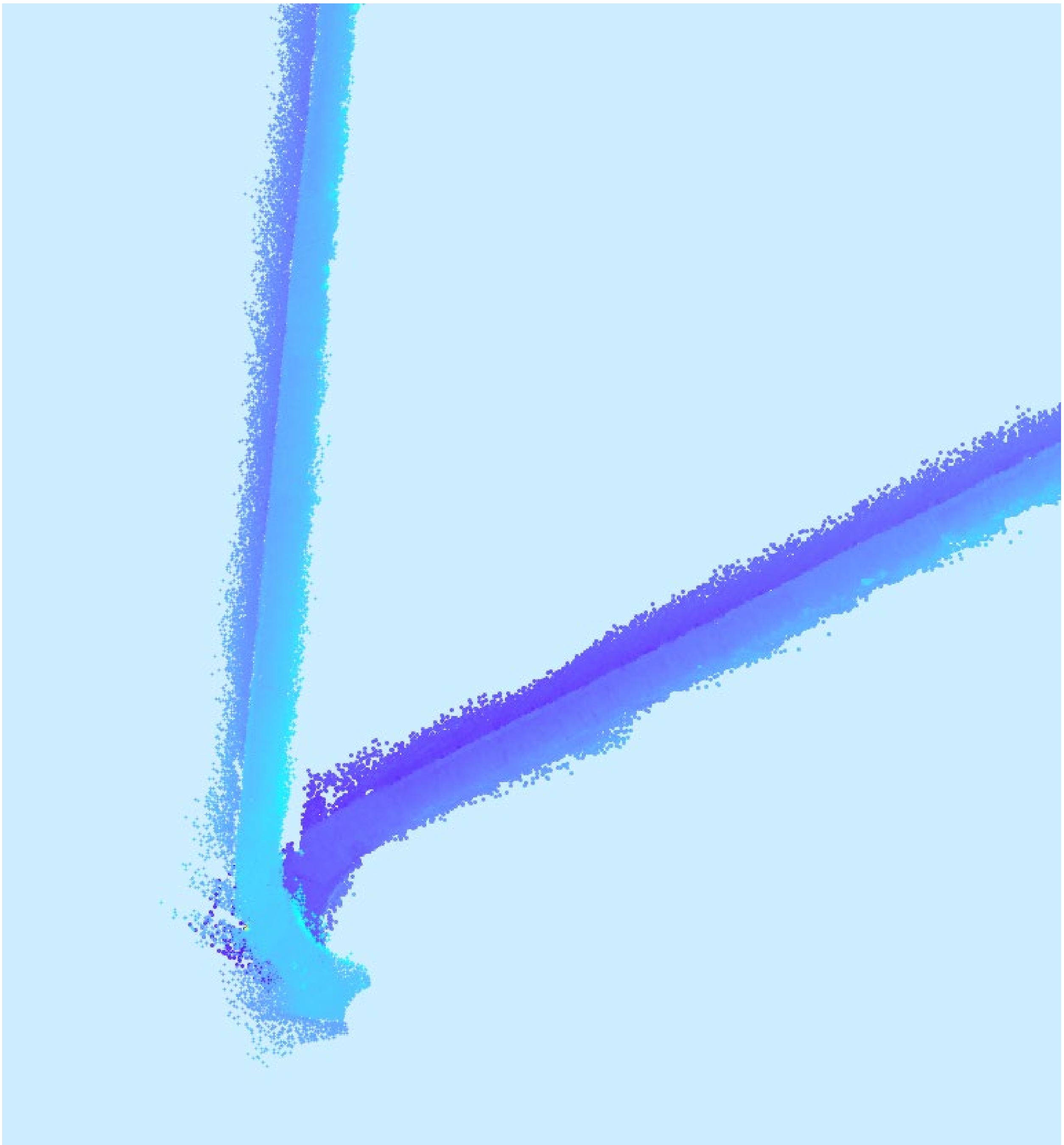


Figure 6.1 iPhone Point Cloud Dataset in Atlantic Ocean on ArcGIS Pro

Another issue encountered with the LiDAR CAD application was its compatibility with AutoCAD Civil 3D. The original DWG output files from the LiDAR CAD application contained point cloud data, mesh data, GPS coordinates, and imagery of sidewalks, curb ramps, and the surrounding terrain. Mesh data represent a polygonal surface that approximates the point cloud data. However, when these DWG files were imported into AutoCAD Civil 3D, multiple error messages appeared and many objects were deleted from the original files before they could be opened. As a result, only the mesh data and GPS coordinates were retained in the modified DWG files in AutoCAD Civil 3D, while the point cloud data and imagery of sidewalks, curb ramps, and the surrounding terrain were missing. This omission created challenges in distinguishing the boundaries of the sidewalks and curb ramps from surrounding features such as grass, private property, and the roadway's curb and gutters. Figure 6.2 below illustrates this issue.

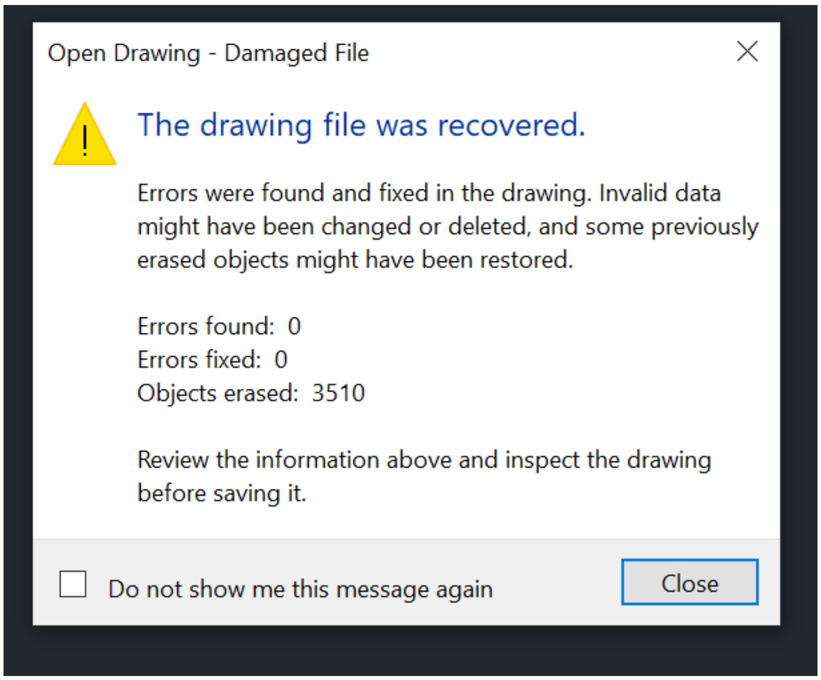


Figure 6.2 AutoCAD Civil 3D Objects Erased

During further consultation, Sandalova explained that the error messages and deleted objects occurred because: 1) the DWG files were generated using the LiDAR CAD application, which is not licensed by AutoDesk, the manufacturer of AutoCAD Civil 3D; and 2) the LiDAR CAD application operates on the Apple operating system, while AutoCAD Civil 3D was running on a Windows operating system. The project did not have the opportunity to explore whether data analysis would have been more effective using AutoCAD Civil 3D on a Mac with the Apple operating system.

Due to the issues encountered with the LiDAR CAD application, the project shifted focus to evaluating another iPhone-based LiDAR application that might be more effective for crowdsourcing LiDAR data. The 3D scanner application was selected for this evaluation. The 3D scanner app offers five scan modes: LiDAR, LiDAR Advanced, Point Cloud, Photos, and TrueDepth. Upon initial review, the LiDAR, LiDAR Advanced, and Point Cloud modes appeared to be the most effective for capturing point cloud data suitable for measuring sidewalks and curb ramps for ADA compliance. The LiDAR scan mode, in particular, was successful in capturing geo-referenced point cloud data. As an experiment, the LiDAR scan mode was used to capture point cloud data of a city block in the Southshore neighborhood of Aurora, Colorado. The sidewalk and curb ramp point cloud data were geo-referenced and accurately positioned when viewed on a street map of Aurora, Colorado, in ArcGIS Pro. Figures 6.3 and 6.4 below provide an illustration of this.

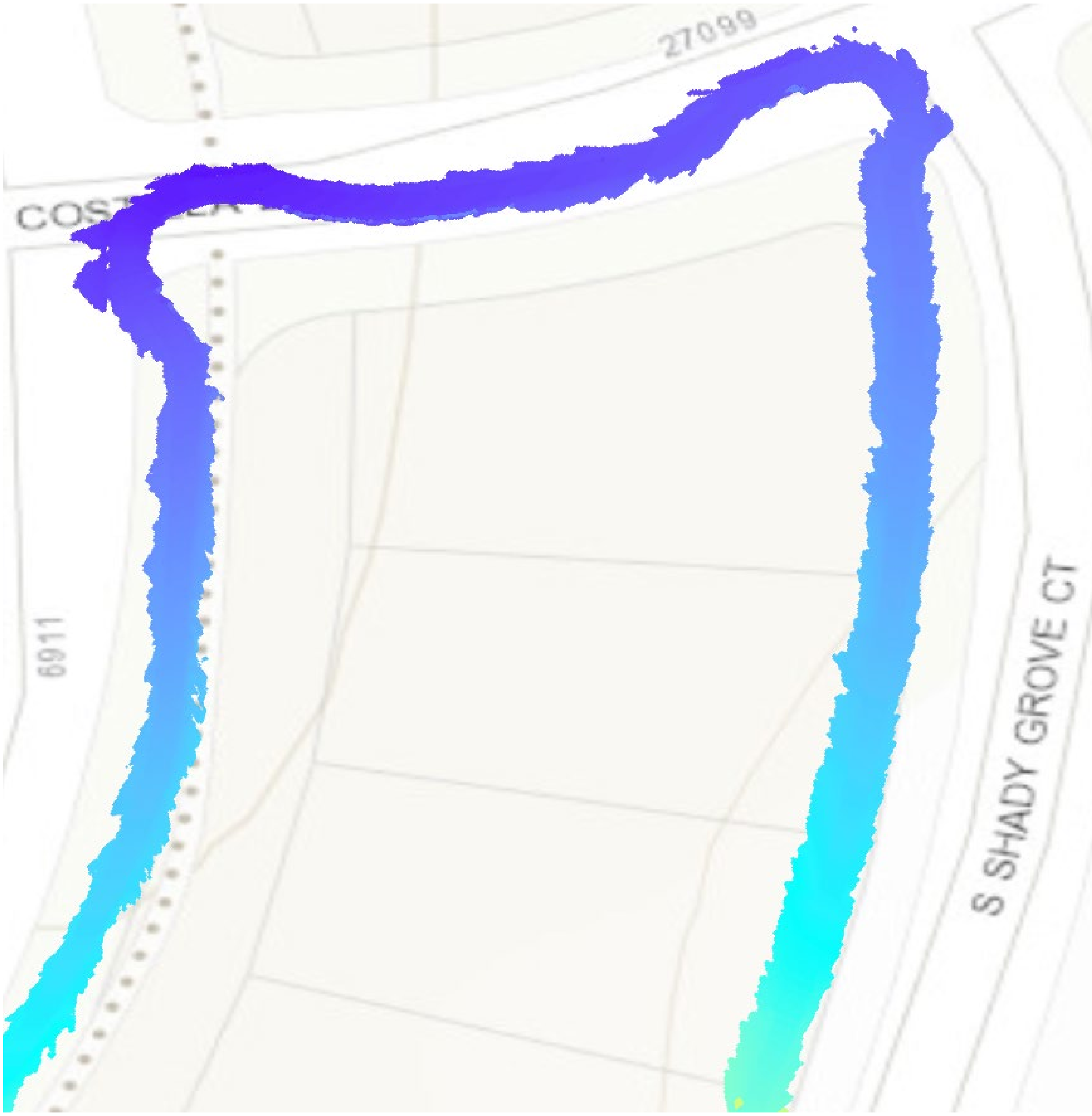


Figure 6.3 iPhone Point Cloud Dataset City Block in Aurora, Colorado, from ArcGIS Pro

Figure 6.4 iPhone Point Cloud Dataset City Block 2 Aurora, Colorado, from ArcGIS Pro

The LiDAR scan mode was limited in that it did not capture RGB colors, making it challenging to measure the point cloud data in Cloud Compare. The next mode evaluated was the Point Cloud scan mode in the 3D scanner application. This mode successfully captured point cloud data of sidewalks and curb ramps with RGB colors, which made it more effective for assessing the infrastructure's ADA compliance. Figure 6.5 shows that this mode allows for the visibility of fine details, such as the tooled joints in concrete sidewalk sections.

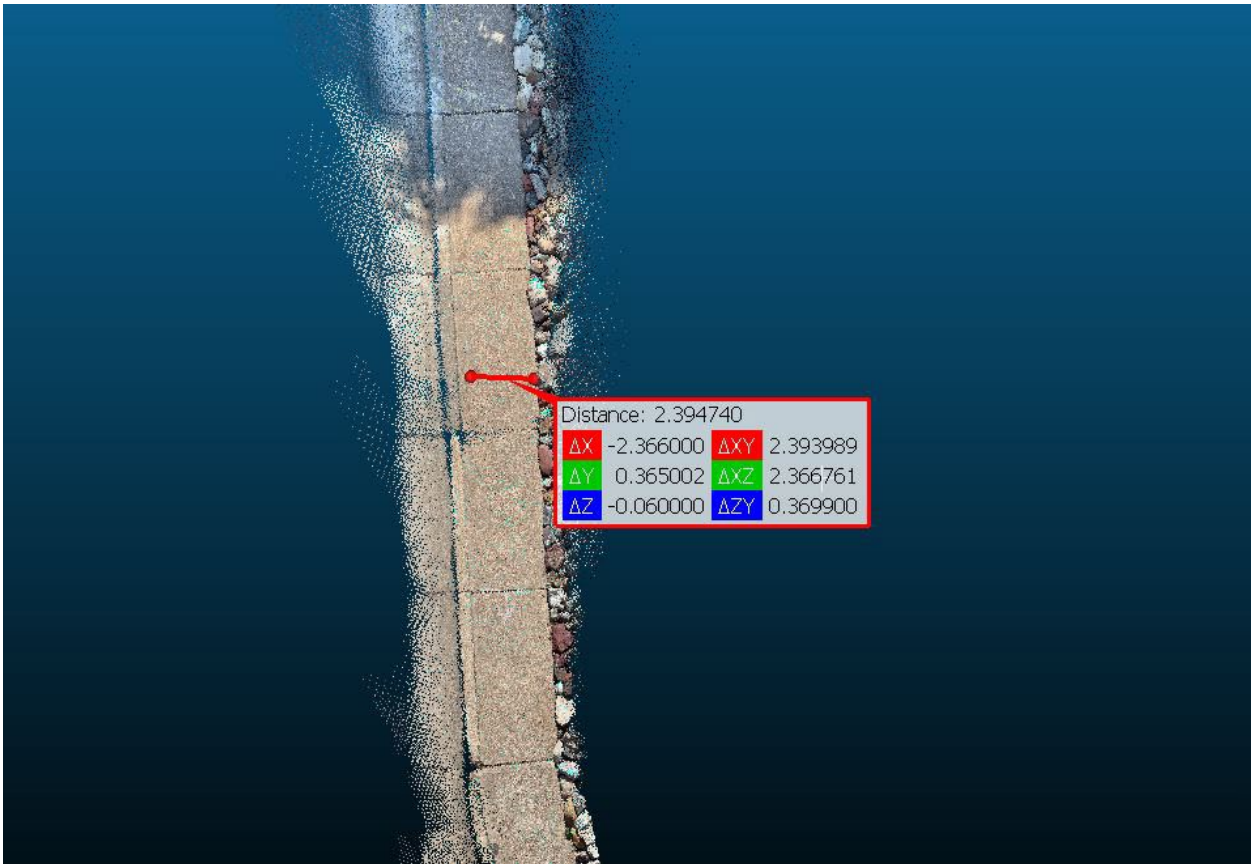


Figure 6.5 iPhone Point Cloud Dataset Sidewalk Plan View in Cloud Compare

The main drawback of the Point Cloud Scan mode on the 3D scanner app was that the data it generated were not geo-referenced, which reduces their effectiveness for crowdsourcing sidewalk and curb ramp point cloud data. The final scan mode evaluated was LiDAR Advanced, which produced geo-referenced point cloud data but still lacked RGB colors, making it less ideal for capturing detailed visual information necessary for crowdsourcing.

The 3D scanner application offers several export options for point cloud data. After consulting with Dr. Chengbo Ai, three export types were identified as effective for analyzing ADA compliance: 1) LAS in meters with color, 2) XYZ color, and 3) XYZ color, space delimited. The project chose the third option for ADA compliance data analysis because it was compatible with Cloud Compare software.

Cloud Compare, an open-source software, was ultimately used for the data analysis. It offered several advantages, including the ability to measure widths, lengths, running slopes, and cross slopes of all sidewalks and curb ramps. Cloud Compare was also effective at identifying small details in the point cloud data, such as ¼-inch lips, which do not meet ADA compliance standards. Based on this experience, we recommend that future researchers use Cloud Compare for point cloud analysis with iPhone LiDAR applications.

There are both advantages and disadvantages to using the LiDAR CAD and 3D scanner applications. The LiDAR CAD app uses feet as the unit of measure, while the 3D scanner app uses meters, necessitating an additional step to convert units to U.S. customary feet during data analysis. Additionally, LiDAR CAD outputs sidewalk data in segments rather than as a complete block, requiring separate analysis for each segment. In contrast, the 3D scanner app can capture an entire city block in a single LiDAR scan, as shown in Figures 6.6 and 6.7 below. Furthermore, the 3D scanner application produces geo-referenced point cloud data, allowing it to be integrated into a GIS platform like ArcGIS Pro, making it more suitable for crowdsourcing due to its geo-referencing capability.

However, one limitation of the 3D scanner application is the inability to find a LiDAR scan mode that captures both RGB colors and geo-referenced data simultaneously. The fact that these features can be captured separately suggests that the necessary technology exists within iPhone LiDAR applications. Despite this, we recommend the 3D scanner application for future iPhone LiDAR research due to its ability to geo-reference data effectively.

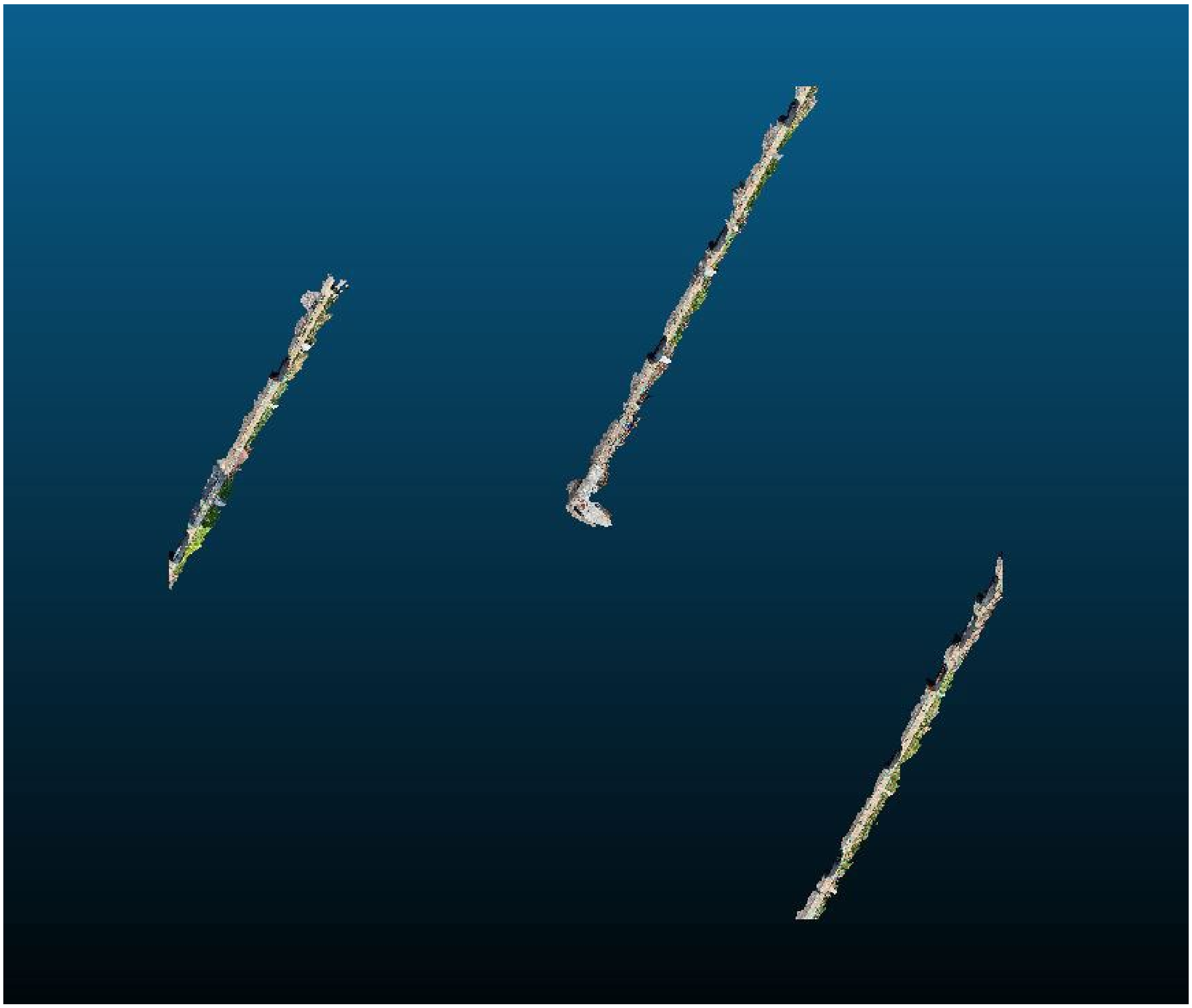


Figure 6.6 iPhone Point Cloud Dataset Sidewalk Segments from LiDAR CAD Application

Figure 6.7 iPhone Point Cloud Dataset Whole City Block from 3D Scanner LiDAR Application

7. CONCLUSIONS

Based on the findings of this research, iPhone LiDAR data prove to be effective in detecting ADA compliance issues along sidewalks and, to a large extent, curb ramps. The iPhone's LiDAR capabilities are particularly adept at identifying vertical changes greater than ¼ inch on sidewalks and measuring the widths of sidewalks and curb ramps. Additionally, the data effectively capture running and cross slopes of sidewalks. However, the accuracy of slope measurements for curb ramps was less consistent, indicating a need for further research to determine whether iPhone LiDAR can reliably detect ADA compliance issues related to curb ramp slopes. When compared with the Trimble TX8, iPhone LiDAR offers several advantages: it collects only the data needed for pedestrian infrastructure, is significantly more time-efficient for data collection, and renders RGB colors in its 3D point cloud models.

It is important to note that the sidewalk ADA checklists covered larger areas, making it easier to identify at least one non-compliant section over an entire block face, as opposed to a single curb ramp. The accuracy of iPhone LiDAR in capturing widths, vertical changes, and slope measurements is important for ensuring ADA-compliant pedestrian infrastructure for individuals with physical disabilities. The literature review of previous pedestrian data collection efforts also provided a foundation for capturing iPhone LiDAR point cloud data. Unlike manual field measurements, iPhone LiDAR data can be collected in minutes and does not require conversion to a digital format. Since the iPhone 12 Pro, released in October 2020, was the first iPhone equipped with LiDAR technology, these applications are still relatively new. While some anomalies in the iPhone LiDAR data for curb ramps led to false ADA issues, there were instances where the iPhone LiDAR curb ramp data matched the manual ADA-related field measurements and Trimble TX8 LiDAR data perfectly, 11 out of 11 times. Further refinement of iPhone LiDAR applications could reduce or eliminate these anomalies.

According to the Centers for Disease Control and Prevention, 13.7% of adults have a mobility disability, a number that continues to grow alongside the need for supportive infrastructure. The results of this research can help guide cities in their ADA compliance efforts. The ability to collect geo-referenced LiDAR data on an iPhone offers the public a means to contribute to data collection efforts for pedestrian infrastructure. If government agencies consider iPhone LiDAR a viable solution, it will be important to establish standardized processes for data collection and analysis to ensure accurate information and minimize misinterpretations. This research aims to pave the way for iPhone LiDAR applications to help bring the nation’s pedestrian infrastructure into ADA compliance, fostering a more equitable transportation system for all.

8. REFERENCES

Ai, Chengbo. 2019. “Improving Pedestrian Infrastructure Inventory in Massachusetts Using

Mobile Lidar.” Massachusetts Department of Transportation. Report No. 19-007.

Ai, Chengbo, Hou, Qing. 2020. “A network-level sidewalk inventory method using mobile LiDAR and deep learning.” *Transportation Research Part C* 119 (2020) 102772. University of Massachusetts.

Ai, Chengbo, Tsai, Yichang. 2016. “Automated Sidewalk Assessment Method for Americans with Disabilities Act Compliance Using Three-Dimensional Mobile Lidar.” *Journal of Transportation Research Board* No. 2542, Transportation Research Board, Washington, D.C., 2016, pp. 25-32.

Apple. 2020. https://www.apple.com/newsroom/2020/10/apple-introduces-iphone-12-pro-and-iphone-12-pro-max-with-5g.

Apple. 2021. https://www.apple.com/newsroom/2021/09/apple-unveils-iphone-13-pro-and-iphone-13-pro-max-more-pro-than-ever-before.

Centers for Disease Control and Prevention. 2020. “Disability Impacts All of Us.” https://www.cdc.gov/ncbddd/disabilityandhealth/infographic-disability-impacts-all.html

ESRI. ArcGIS Desktop. https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/what-is-a-las-dataset-.htm.

ESRI. ArcGIS Desktop. https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/types-of-lidar.htm.

Eisenberg et al. 2020. “Are Communities in the United States Planning for Pedestrians with Disabilities? Findings From a Systematic Evaluation of Local Government Barrier Removal Plans.” *Cities: The International Journal of Urban Policy and Planning* Volume 102. https://www.sciencedirect.com/science/article/pii/S0264275119302501#!

Frackelton et al. 2013. “Measuring Walkability: Development of an Automated Sidewalk Quality Assessment Tool.” *Suburban Sustainability*: Vol. 1. Iss. 1, Article 4. https://scholarcommons.usf.edu/subsust/vol1/iss1/4.

Geoslam. 2022. “Point Clouds for Beginners.” https://geoslam.com/point-clouds/.

Jacobs Engineering Group. “ADA Transition Plans: A Guide to Best Management Practices.” National Cooperative Highway Research Program. NHCRP Project Number 20-7 (232).

Loewenherz, Franz. 2010. “Bellevue’s ADA Sidewalk and Curb Ramp Compliance Program.” City of Bellevue, Washington. Washington State LTAP News.

New Jersey Department of Transportation. (2006). “County Road Sidewalk Inventory, New Jersey.” https://www.state.nj.us/transportation/refdata/countysidewalks/.

Turkan et al. 2022. “Automated Localization and Functional Condition Assessment of ADA Curb Ramps with Mobile LiDAR Point Clouds.” Oregon State University. Pacific Northwest Transportation Consortium (PacTrans). USDOT University Transportation Center for Federal Region 10.

Quiroga, Cesar, Turner, Shawn. 2008. "ADA Compliance at Transportation Agencies: A Review of Practices." National Cooperative Highway Research Program. NCHRP Project 20-07, Task 249. Transportation Research Board. Texas Transportation Institute. The Texas A&M University System.

United States Access Board. "Guide to the ADA Accessibility Standards." https://www.access-board.gov/ada/guides/chapter-4-ramps-and-curb-ramps.

United States Department of Justice. 2010. "2010 ADA Standards for Accessible Design."

United States Department of Justice Civil Rights Division. www.ada.gov.

United States Geological Survey. https://www.usgs.gov/faqs/what-lidar-data-and-where-can-i-download-it.

PART 2: EVALUATING OBSTRUCTIONS & THE ADA COMPLIANCE OF SIDEWALKS USING LIDAR TECHNOLOGY

9. INTRODUCTION

Sidewalks are essential infrastructure for pedestrians, particularly those with disabilities. A sidewalk's condition has a significant influence on wheelchair users' everyday life, and it helps them to safely travel without interruptions (Ai and Tsai 2016). Based on the 2010 U.S. Census, "there are more than 3.6 million people with disabilities using wheelchairs on a daily basis for mobility" (American Fact Finder Survey). Additionally, it can be dangerous to travel if there are gaps in the sidewalks or there is poor infrastructure. There are set regulations for how a sidewalk should be constructed to accommodate people with disabilities, and transportation agencies are responsible for verifying that sidewalks comply with the Americans with Disabilities Act (ADA). It is their responsibility to ensure ADA compliance and to maintain the sidewalks on a regular basis, but there are sidewalks that are not ADA compliant because they were constructed before the ADA regulations were enacted in 1990.

Transportation agencies typically use a traditional and manual method to examine the sidewalks, but the process is extremely time consuming and labor intensive (Tsai et al. 2013). For this reason, it is important to explore new solutions using modern technology such as light detection and ranging (LiDAR) mounted to a vehicle. This is called mobile LiDAR sensing. It would be an affordable approach to analyzing the ADA compliance of sidewalks because there are many companies in the self-automated car industry that are actively collecting mobile LiDAR for improving their vehicles' safety (Zhao and Yuan 2012). Their mobile LiDAR data analyze curbs and roads and inadvertently collect sidewalk data, so it is important to determine if this massive collection of data can effectively verify ADA compliance of sidewalks.

The focus of this paper will be on the use of mobile LiDAR data for verifying ADA compliance of sidewalks in a small residential neighborhood in Denver, Colorado. This master's thesis examines which ADA regulations can be analyzed from mobile LiDAR data, as well as analyzing the impacts of different types of obstructions that may cause gaps in sidewalk data. Ultimately, the goal is to determine the percentage of data gaps caused by each type of obstruction in mobile LiDAR data. Obstructions refer to anything blocking the view of the sidewalk from the vehicle's perspective, such as trees, parked cars, vegetation, and poles.

The project involves post-processing two point cloud files in .las file format, one collected from a mobile LiDAR sensor and the other collected from a backpack LiDAR sensor. As a control group, the backpack LiDAR sensor was collected by another person who walked along the sidewalks as to avoid gaps in the data. If there are minimal obstructions in the mobile LiDAR data, the sidewalks and curb ramps can be isolated, classified, and the metrics regarding ADA compliance can be extrapolated within the point clouds. Tables 9.1 and 9.2 illustrate some of the ADA regulations regarding sidewalks and curb ramps (Tsai et al. 2013).

Table 9.1 ADA Compliant Curb Ramp Requirements

(Based on 2010 ADA Standards for Accessible Design)

Check Number	Measurement
1	Running Slope < 1:12
2	Cross Slope < 1:48
3	Width ≥ 36 inches
4	Curb Ramp Landing ≥ 36 inches length
5	Curb Ramp Landing ≥ Width of Curb Ramp
6	Curb Ramp Landing < 1:48 slope all directions
7	Curb Ramp Flares < 1:10
8	Counter Slope of Curb and Gutter < 1:20

Table 9.2 ADA Compliant Sidewalk Requirements

(Based on 2010 ADA Standards for Accessbile Design)

Check Number	Measurement
1	Width ≥ 36 inches
2	Passing Space 60"x60" every 200 feet
3	Running Slope < 1:20
4	Cross Slope < 1:48
5	Vertical Height < 1/4 Inch

This project focuses on five of the ADA regulations—verifying if the lip of the curb ramps is less than a ¼-inch tall, the counter slope of the curb ramps is less than 1:20, and assuring the compliance of the width, cross-slope, and running slope of the curb ramps and sidewalks. There are many sidewalks and curb ramps that do not comply with ADA regulations, so utilizing a vehicle-driven, mobile LiDAR sensor can save time and money compared with traditional methods. Thus, it is imperative to determine how obstructions affect the data quality of mobile LiDAR data.

The following is the methodology to measure the impacts of varying obstructions in mobile LiDAR data, and to identify the ADA compliance of sidewalks and curb ramps.

10. METHODOLOGY

During the post-processing phase, the point clouds were filtered to remove noise and outliers, and off-ground points like trees and buildings were removed during the offset filtering steps. The point clouds were then colorized using a GeoTIFF with tools provided in Global Mapper. Sidewalks and curb ramps were isolated for data analysis. Additionally, there were attempts to automate the processes of curb detection and identifying sidewalk cracks greater than ¼ inch in height using Python's PDAL.

The following tools were used in throughout the project:

- Cloud Compare
- Global Mapper
- QGIS
- Google Earth Pro

Optional tools:

- PDAL
- Saga GIS
- Grass GIS

10.1 Removing Noise and Outliers

To remove noise and outliers using Cloud Compare, navigate to the tools menu, select "Clean," and then choose the SOR filter (statistical outlier removal). Adjust the settings for removing outliers; in this case, the default settings were initially used. These settings can be modified to test how many outliers are removed, and the noise filter can also be adjusted to fine-tune the removal process. The settings were then adjusted to 10 points with a standard deviation multiplier of 5, which helped preserve the integrity of features such as tall trees with less point cloud density.

Next, the SOR filter was updated to 100 points with a standard deviation multiplier of 5, which further improved the visibility of foliage and roads. However, switching the standard deviation multiplier to 1 overly filtered the features, removing many of them. The optimal layer was then selected, which used the settings of 100 points with a standard deviation multiplier of 5. After selecting this layer, return to the tools menu, choose "Clean," and select "Noise filter."

The KNN option allows you to set the number of points for a new plane instead of a sphere. However, using the "Radius" option with a sphere was found to be more accurate. The "Relative" option adjusts the standard deviation multiplier to give the best result, enhancing clarity. This adjustment is crucial because point cloud data (PCD) can have internal variations. Selecting "Absolute" repairs every part of the PCD, while selecting "Remove isolated points" removes all points with six or fewer surrounding points. The suggested radius value is typically the best for the specific PCD being processed.

After applying the suggested settings and selecting "Remove isolated points," this process was performed on the clone layer for "sidewalk_classified1.laz.clone." As shown in Figure 10.1, the noise cleaning tool successfully removed noise and certain objects, such as trees, possibly thinning other trees as well. The next steps involved repeating the process while adjusting the settings for optimal results. For example, a radius of 0.06 with a standard deviation multiplier of 1 was found to be too aggressive, thinning out the data entirely. A radius of 0.15 with a standard deviation of 0.9 was better but still thinned the data too much. Testing a larger radius with a standard deviation of 5, followed by the same radius with a standard deviation of 1, led to better results. After further adjustments, it was found that a radius of 1.0 with a standard deviation of 5 worked well, while other combinations either cut out too many points or did not improve the noise removal.

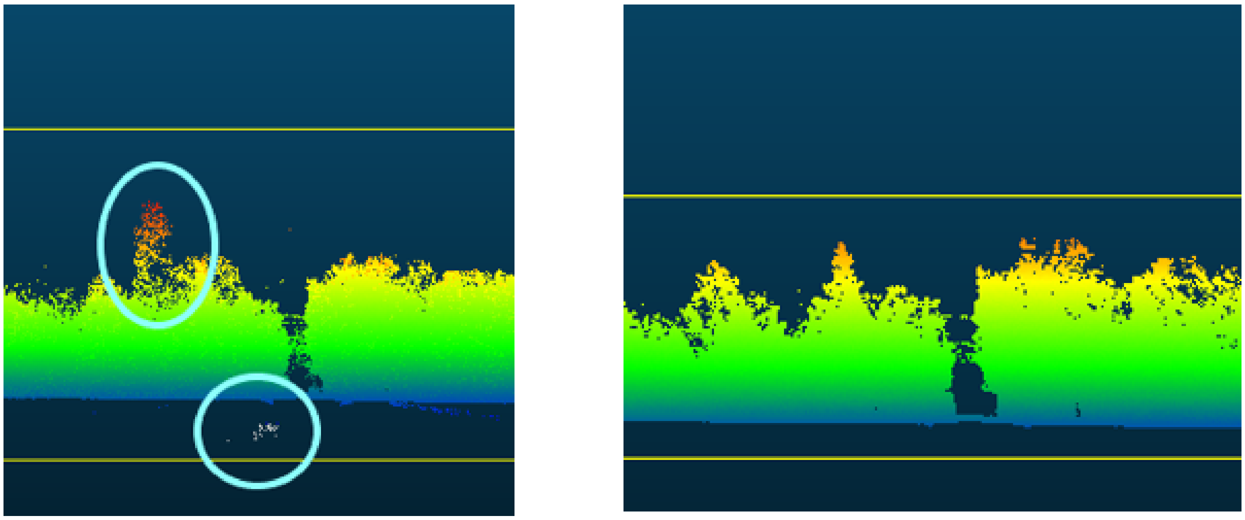


Figure 10.1 Objects Deleted with Noise Cleaning Tool

Finally, the same outlier and noise filters, with the "Remove isolated points" option selected, were applied to the "road.las" file.

10.2 Elevation and Lateral Offset Filtering

To perform elevation and lateral offset filtering, begin with the elevation offset filtering process for classifying ground points. In Cloud Compare, with the target data layer selected, navigate to the plugin menu and choose the CSF Filter. Select the "flat" option and click OK. Repeat these steps for both the sidewalk and road data layers. Note that some areas may still contain noise above the sidewalk, possibly due to foliage hanging over the sidewalk that the CSF ground filter did not catch.

Next, open the .las files in Global Mapper and activate the 3D view. Use the 3D navigation tool to easily move around the point cloud and inspect it for any remaining noise or outliers, as shown in Figure 10.2. For any noise that should be removed from the ground layer, use the drawing tool to draw a rectangle around the noise to select it, ensuring that the sidewalk layer is not also selected. Switching to 3D mode can help better visualize the point cloud. Once the noise is selected, assign it to classification #0, classifying it as unclassified low vegetation. To save the file, go to the file menu, select "export," then choose "export vector/LiDAR format," select .las, and save it to the desired folder.

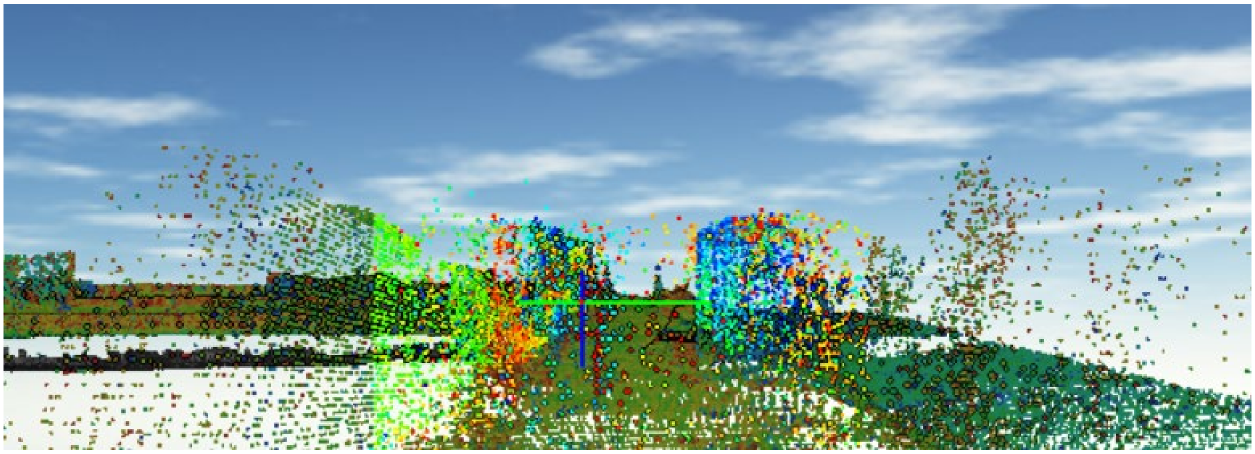


Figure 10.2 Global Mapper 3D View

For lateral offset filtering, which involves manually removing points, start by selecting the "ground-points.sidewalk.las" file and setting the active mode to intensity to highlight the sidewalks. Change the color scale to "topo landserf," as shown in Figure 10.3. Use the segment tool to create a rectangle around the outer edges of the sidewalk, doing your best to select points centered on the road and ensuring that the lines are straight. Once the rectangle is created, use the tool to export the polyline. Then, click the green checkmark to perform the segment after selecting "segment out."

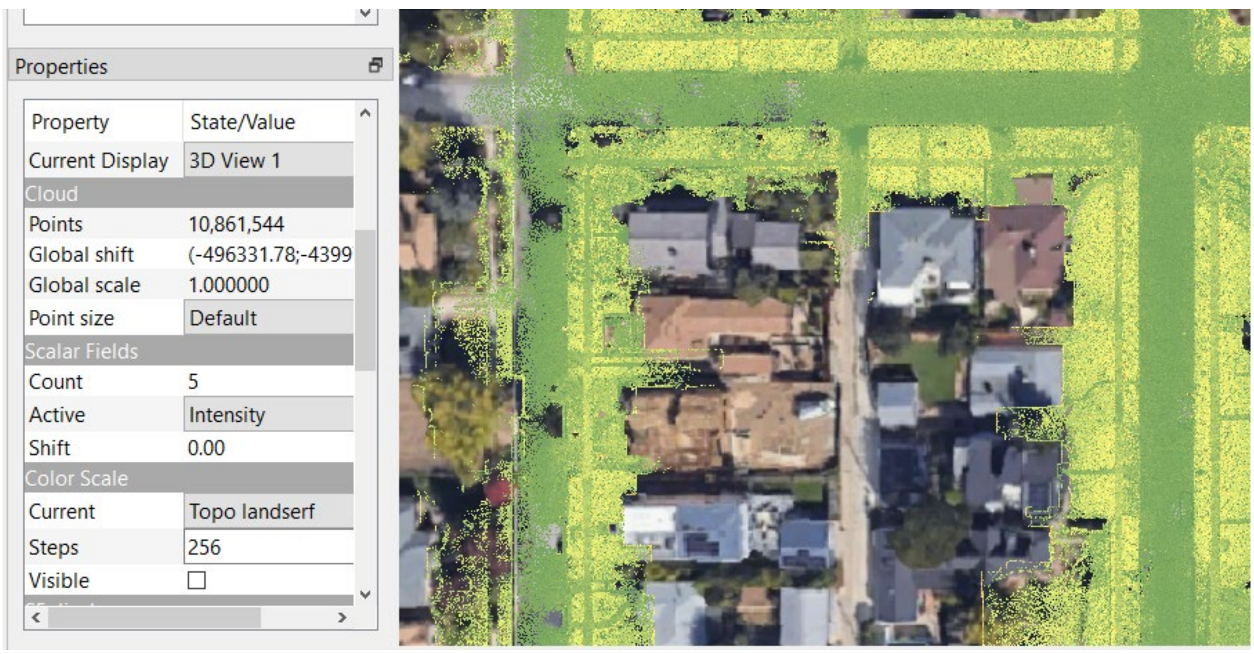


Figure 10.3 Color Scale

Next, select the other point cloud, “ground-points-road.las,” and use the segment tool again. Import the previously exported polyline using the “import polyline from DB” tool. This relates to the outline polyline segmentation. Select segment out, then click OK. This process will create two layers: the undesired layer named “segmented in” and the layer of interest named “segmented out.”

Within the sidewalk data folder, create a new group named “Q1” for quadrant 1 by right-clicking the sidewalk folder, adding an empty group, and renaming it by double-clicking the new group. Clone the new layer, select the clone, and open the segment tool. Since the outline color of the polyline is green, it is recommended to change the color of the layers to “brown > yellow” to improve visibility.

Zoom into the top-right corner and create a rectangle around the data within that block. Ensure the lines are straight to accurately define the area. Once the rectangle is created, use the segment out tool to export the polyline. Afterward, select the segment out tool and click the green checkmark to finalize the newly segmented layers.

Next, select the segmented road layer and import the polyline using the import polyline from DB tool. Repeat these steps (9–14) for the remaining quadrants: Q2 (top-right corner), Q3 (bottom-left corner), and Q4 (bottom-right corner). By the end of this process, both the sidewalk and road data will have identical shapes, refined through elevation and lateral offset filtering.

The final result, as seen in Figure 10.4, will show the sidewalk and road data before and after applying lateral offset filtering, with the cleaned and segmented data now ready for further analysis or use.

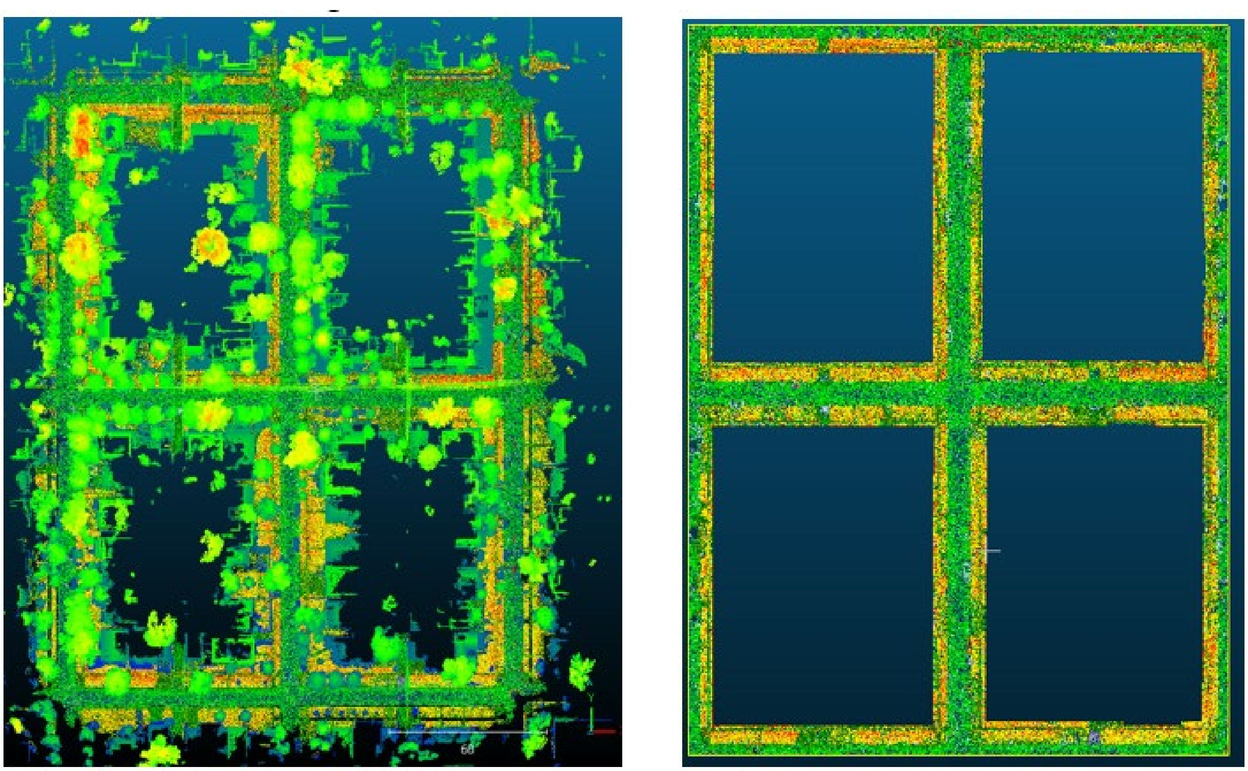


Figure 10.4 Lateral Offset Filtering Before-and-After Image

10.3 Adding Color to LiDAR Data

To add color to LiDAR data, begin by collecting imagery via Google Earth. Start by opening Google Earth Pro. When downloading JPG images from Google Earth, make sure to turn off all unnecessary layers to improve image quality. If the imagery contains obstructions such as trees, consider using an alternative data source, like the Denver Regional Aerial Photography Project, available at DRCOG's dataset.

Next, geo-reference the imagery and create a GeoTIFF using QGIS. Open QGIS and download the Google Earth base map. Then, open the "Add Raster for Interactive Georeferencing" tool by navigating to Layer -> Georeferencer Tool -> Open Raster. This will open the image, allowing you to place it side by side with the QGIS Google Earth image. Click on a target point, select "Canvas from Map," and then choose the corresponding point from the map. Continue adding points until geo-referencing is complete. Once finished, export the image, import it into Global Mapper to add color to the point cloud, then re-export it. Upload the image into QGIS to ensure the projection is set to EPSG 32613 before importing it into Cloud Compare.

For adding color to point clouds via Global Mapper, start by opening the georeferenced GeoTIFF [e.g., GoogleEarth(2)] in Global Mapper. Save the projection of the sidewalk data. Double-click the GeoTIFF to open its properties, go to the Projection tab, select "Load from File," and choose the correct file. Click OK. Next, open the "Apply Color to LiDAR Points" tool, select the appropriate files, and run the tool. Repeat this process for the LiDAR data collected from mobile road data. Once completed, export the file, upload it into QGIS to verify the projection is set to EPSG 32613, and then import it into Cloud Compare. Your LiDAR data should now be colorized and ready for further use.

10.4 Isolating the Sidewalk and Curb Ramp Data

To isolate the sidewalk and curb ramp data, start by manually classifying the sidewalks and curb ramps in Global Mapper. Note that the Global Mapper train classifier is only available in the PRO version. Begin by opening Global Mapper and then uploading your data file by selecting "Open -> Data File" and choosing the relevant file. When the upload window appears, select "Color by Intensity" for the draw mode to improve contrast, and choose "Use Selected Terrain Shader." Once done, click OK.

Next, select the tool to specify new LiDAR classifications. For the sidewalk classification, set it to 22 and click OK. While you can create a new classification called "Model Key Point" using the "Model Key Point" tool, it is advised not to use this option. To add the curb ramp classification, open the appropriate tool shown in Figure 10.5 and set the classification to 0 for the current state and 23 for the new curb ramp classification.

Afterward, open the tool again and change classification 23 to classification 2, which moves the ground points to classification 2. Once the data are loaded into the workspace, click on the "Filter LiDAR Data" tool and ensure classifications 0, 2, 22, and 23 are selected. The data may disappear momentarily, but this step will highlight all the necessary data.

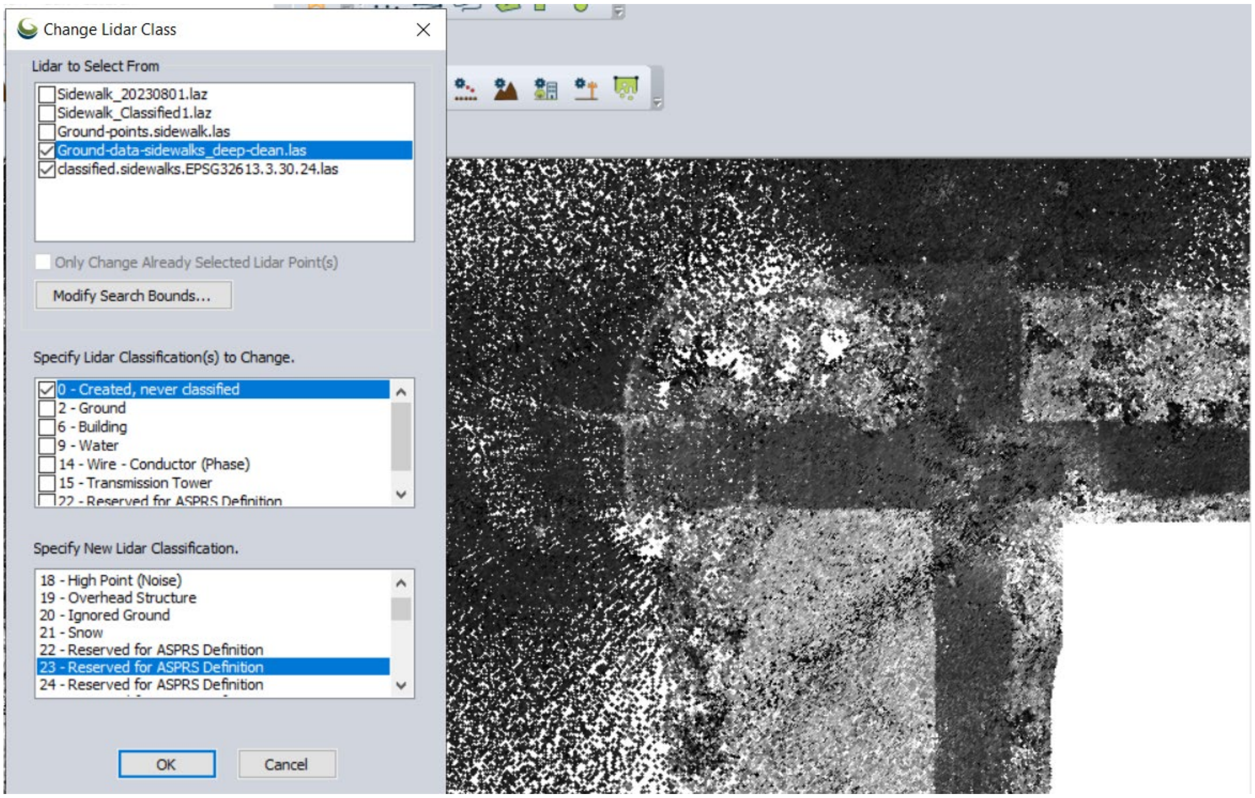


Figure 10.5 Change LiDAR Class

Now, use the "Select by Drawing Polygon" tool to create a polygon around the sidewalks, as shown in Figure 10.6. Right-click to close the polygon, and you will notice the highlighted area turns red. If you missed some sidewalk data, you could add more later if needed. Right-click anywhere in the mapping window, choose "Edit -> Edit Selected Features," and update the highlighted data to classification #22. Repeat this process for other areas of the point cloud, classifying any curb ramps as classification #23.

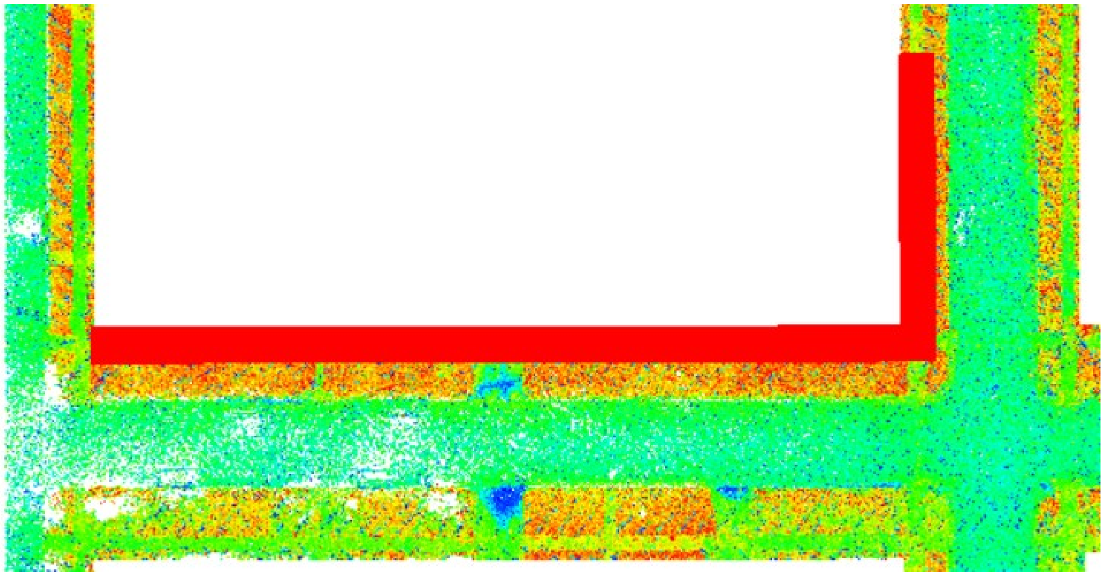


Figure 10.6 Polygon around Sidewalk

Continue selecting sidewalk features in Global Mapper from an aerial view until all sidewalk data are classified as #22. If other points were selected during the 2D aerial classification phase, switch to 3D mode. Use the walking-person tool to navigate the sidewalks and check for any outliers within the sidewalk-classified data. If points are misclassified, use the “Draw Tool,” as shown in Figure 10.7, to isolate those points, then reclassify them to either 22 (sidewalk) or 23 (curb ramp). Continue this process until all data are correctly classified and all outliers are removed.

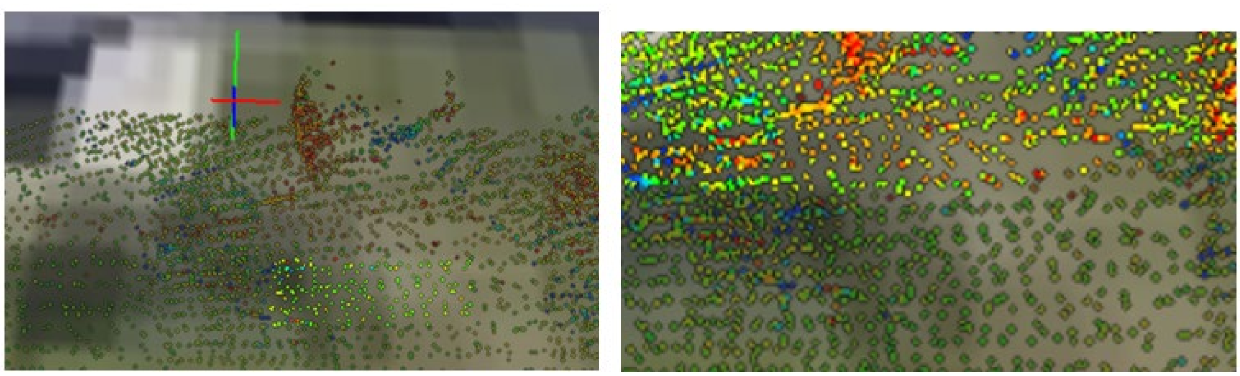


Figure 10.7 Outlier Detection

Once all selections are made, re-highlight the sidewalk data by clicking the “Select LiDAR Class” tool, selecting classification 22 and clicking OK. Analyze the data in 3D mode to ensure no additional outliers remain. Manually classifying the data is often the simplest and most accurate approach, although it can be time consuming. In some cases, auto-classifying vegetation and outliers can be a quicker alternative.

To auto-classify low to medium vegetation in Global Mapper, start by making sure both the road and sidewalk offset filtering layers are uploaded. Make a copy of the two layers, highlight the points classified as ground, and change their classification from 2 to 0. Open the auto-classify tool and adjust the settings for classifying vegetation, then click OK. If this method does not work perfectly, delete the layers, make a new copy, and try again, adjusting the max height settings as needed. Once the vegetation is classified correctly, return to 3D view to refine the classifications, as shown in Figure 10.8, particularly along the edges of the sidewalks. Be sure to classify any vegetation overhanging the sidewalk as 0, as shown in Figure 10.9.

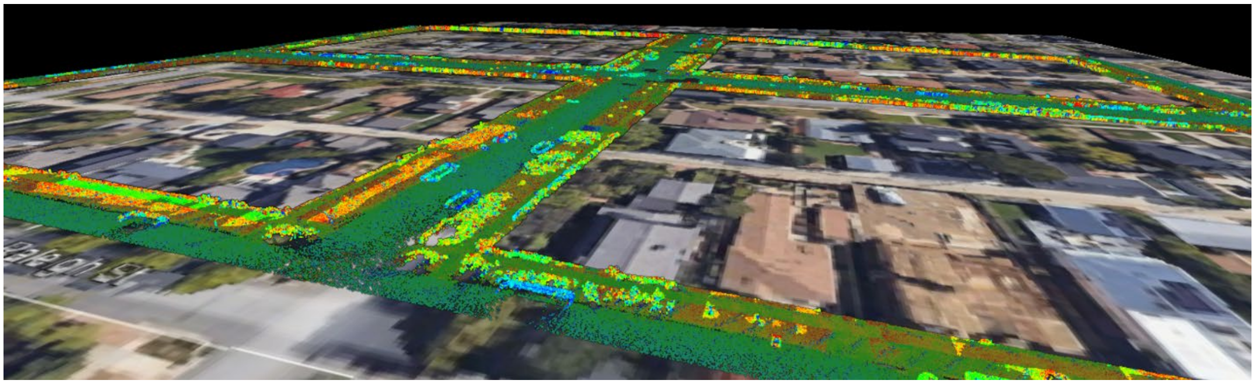


Figure 10.8 3D View

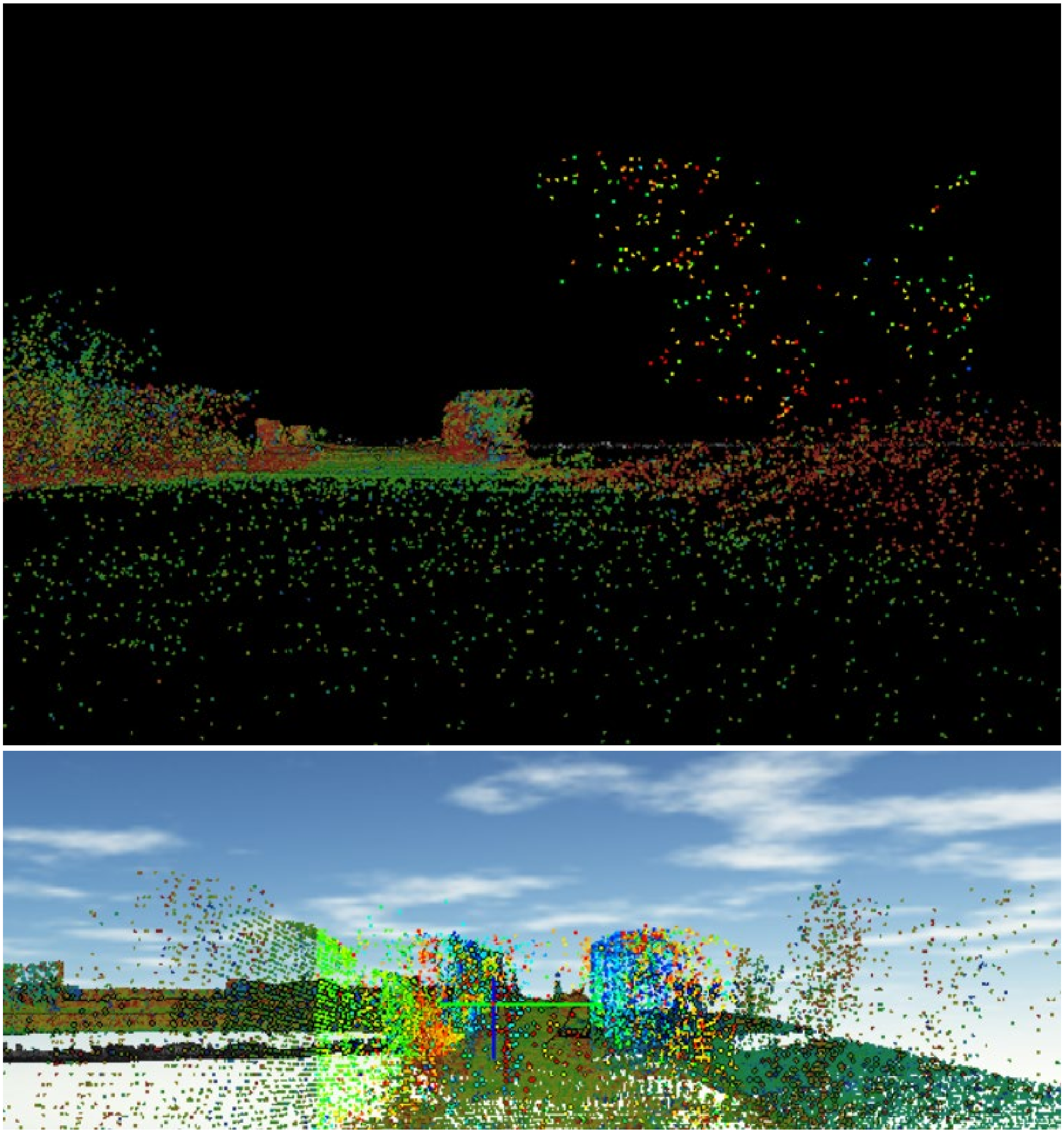


Figure 10.9 Vegetation Identification

After updating the classifications to either 22 or 23, repeat the process for other areas of the point cloud. Once all data are classified and outliers removed, re-highlight the sidewalk data, analyze them in 3D mode, and make any final adjustments. Review the .las files to ensure no unclassified vegetation remains as this can affect the data when imported into Cloud Compare, as shown in Figure 10.10.

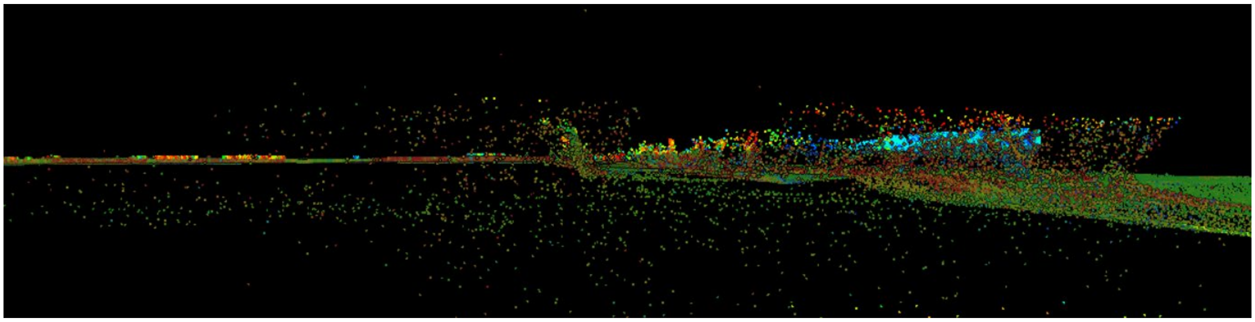


Figure 10.10 Marking Unclassified Data

To isolate the sidewalk and curb ramp data in Cloud Compare, start by exporting the files from Global Mapper and importing them into Cloud Compare for classification. Organize the files into quadrants (e.g., Q1 for the top-right block, Q2 for the top-left block, etc.), which will assist in the upcoming steps. Change the Scalar Field (SF) to classification, and use the "Filter by Points" tool to select classification 0, then split the data.

Next, use the segment tool to segment the top, bottom, left, and right sections of the sidewalk for each of the four blocks, as shown in Figure 9.11. Name each segment based on its quadrant and placement, such as Q1S1TOP for quadrant 1, section 1, top location. Use the segmented polyline to construct a single layer of the four quadrants for both the sidewalk and road-collected .las files. Classify the entire layer as sidewalk and repeat the steps for curb ramps.

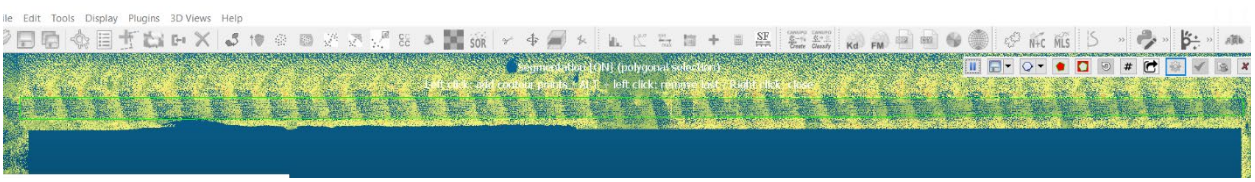


Figure 10.11 Segment Tool

Once done, return to the sidewalk data, clone them, and move them to the Q1 folder for segmentation. Open the segmentation tool with the target layer selected, use the "Select Polyline" tool to select the corresponding segment (e.g., Q1S1TOP), and click "Segment In," then confirm with the green checkmark, as shown in Figure 10.12. Repeat this for all segments in each quadrant.

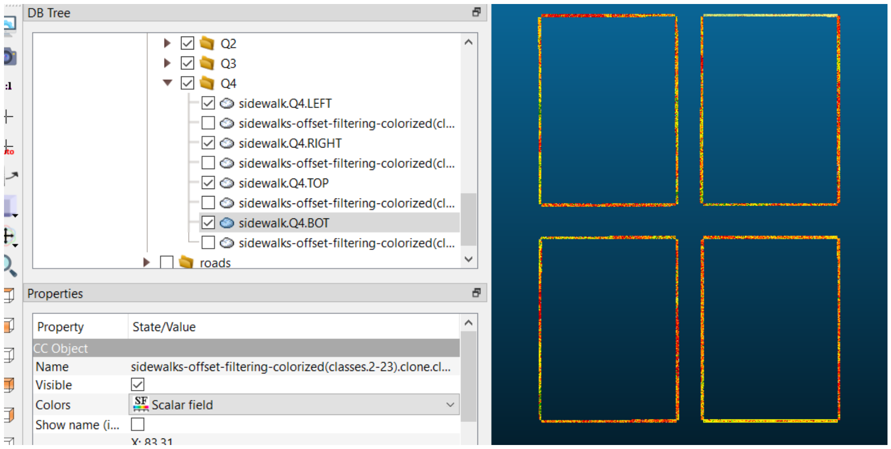


Figure 10.12 Segment In Tool

Continue this process for every quadrant, making sure to clone the unsegmented layer each time for every section of each quadrant. Rename the layers of interest as sidewalk.Q1TOP, sidewalk.Q1BOT, etc. to maintain consistency. Once all segments are created, select the 16 layers for the four quadrants, clone them, and go to Edit -> Merge. Repeat these steps for the road-collected LiDAR .las data as well as the curb ramp data to complete the process.

10.5 Measuring Gap Counts Caused By Obstructions

To measure the gap count caused by obstructions, begin by calculating the total gaps in data using QGIS. First, open Cloud Compare and select the polylines associated with the sidewalks. Export these polylines as a single shapefile by navigating to File -> Save -> Save to Folder. Note that using the merge tool to create a single layer of the polylines may not work as expected.

If the polylines do not align correctly with the data, return to Cloud Compare and manually adjust them using the translate/rotate tool to align them with the isolated sidewalk data. With the polyline selected, right-click in the window to move it freely, zooming in to ensure that the point clouds are properly contained within the area. Rotations can be performed using the left mouse click.

Next, open QGIS and upload the roads-isolated.las, sidewalks-isolated.las, and sidewalks-polylines.shp files. In the advanced settings, set a small increment for translation to fine tune the rotation on a micro scale. Use the Tx or Ty isolation to move the data along a single plane, ensuring Tz is unchecked. If errors occur, try loading an older backup version of the Cloud Compare project file, which might resolve the issue.

To fill the polylines created in QGIS, use the “Lines to Polygons” tool and save the result as “sidewalks-polygon.shp.” Convert the road-collected .las points to vector points by saving the file as a .shp file, naming it “mobile.isolated-sidewalks.” Repeat this process for the sidewalk-collected .las points, naming the file “sidewalks-isolated.” In QGIS, open these files by selecting Layer -> Add Layer -> Add Vector Layer. The backpack-collected data will appear as light-brown, and the mobile-collected points clouds will be pink in vector form, as shown in Figure 10.13.

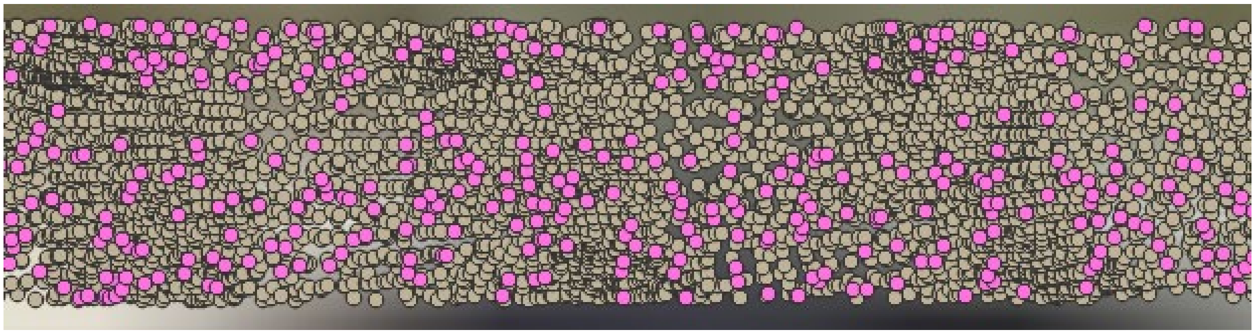


Figure 10.13 Backpack-Collected Data

Set the projection to EPSG 32613 by double-clicking the layer and going to the Source tab. Buffer the vectored points with a point size of 4 inches, ensuring the "Dissolve Result" option is selected. Save this as a temporary file, then dissolve the layer, again saving as a temporary file. Clip the dissolved layer to the polygon and save this as a temporary file as well.

To obtain the difference in area between the .las file converted to vector and the polygon representing the sidewalks, perform a "difference" operation on the clipped and polygon layers, saving the result as a temporary file. To add the area for each polygon within a layer, use the "Add Geometry Info" tool and save the file so the layers for clipped, difference, and the original polygon representing the polylines are not temporary.

Open the "Basic Statistics for Fields" tool, select the polygons layer, and choose "Area" as the field to calculate for the polygons layer and the clipped/difference layer. The statistics will display the total area, with the total sidewalk polygon showing 2,083.95 square meters and the difference from the roads data showing 650.60 square meters. To calculate the percentage of gaps, use the equation:

$$\text{Gap Percentage (of the mobile road data)} = \left(\frac{\text{"Polygon Area"} - \text{"Clipped Area"}}{\text{"Polygon Area"}} \right) \times 100$$

For example, if the polygon area is 2,083.199 square meters and the clipped area is 1,836.550 square meters:

$$\text{Gap Percentage} = \left(\frac{246.649}{2083.199} \right) \times 100 = 11.84\%$$

This indicates that the clipped data covers 88.16% of the sidewalk, with a gap percentage of 11.84%. Repeat these steps for the backpack-collected data, where the clipped data cover 97.32% of the sidewalk, with a gap percentage of 2.68%. At this point, save the files permanently to ensure the area for each layer is retained. Automating this process with a PDAL program to determine the percent coverage of the polyline data subtracted by the new clipped layer would be a great enhancement.

For calculating the percentage of data gap for each obstruction type, first align the roads data with the sidewalks data using the align tool and points on the maps, as shown in Figure 10.14. Minor adjustments can be made manually with the translate/rotate tool. To display the obstructions clearly, load the individual layers for class 0, representing low vegetation around the sidewalks, and load the off-ground layer to show trees and other objects. Cars will show up in both class 0 and the off-ground layer.

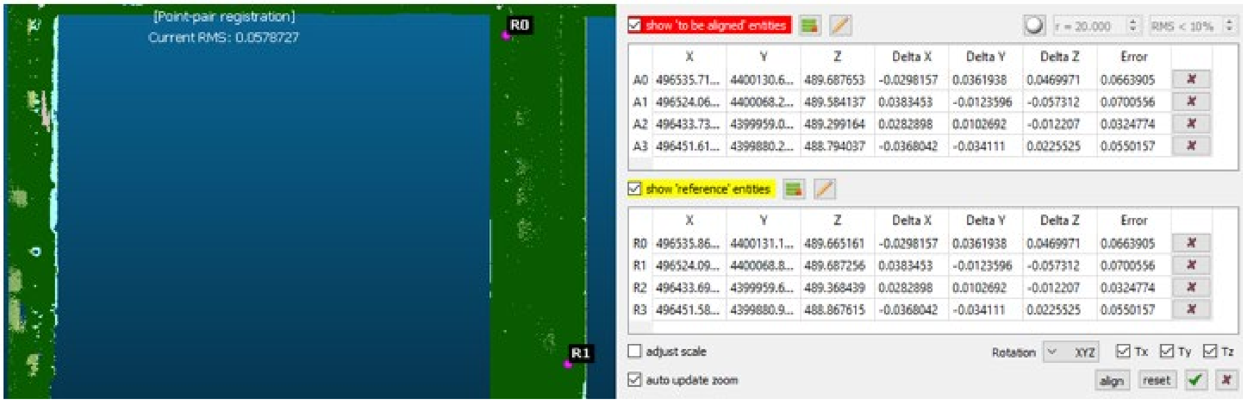


Figure 10.14 Calculating Percent Data Gaps Caused by Obstruction

Next, open the sidewalks-isolated data from the backpack data and color them in a dark purple (vidris) as a backdrop. Select the mobile roads data, change the point size to two, and set the SF to classification with a bright white color for contrast. Use the segment tool to draw a polyline around the obstruction and the area of the sidewalk that contains a gap in data, as shown in Figure 10.15. Then, right-click to close the polygon. Export the results and exit the tool.

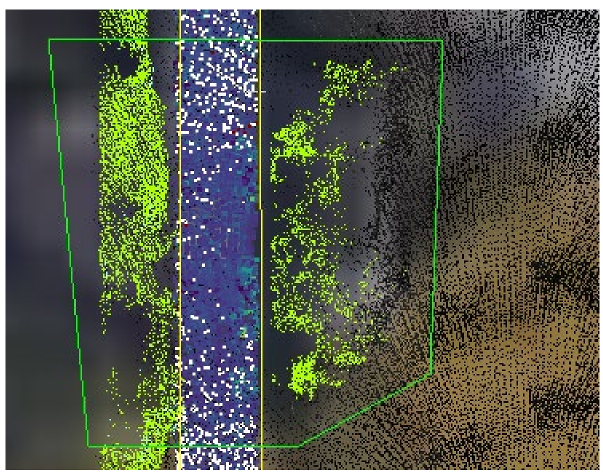


Figure 10.15 Polyline Around Obstruction

Create a table of groups within the DB Tree to organize each polyline into different groups representing the various obstruction types. Name the newly created polylines according to the obstruction they pertain to, the quadrant they are in, the segment number for that particular obstruction type (e.g., S2 for segment 2), and the side of the quadrant it falls on (e.g., top, bottom, left, or right). Repeat this process for every data gap in the mobile LiDAR data.

Double-check the classification by viewing it in the off-ground layer in Cloud Compare, or by importing it into Global Mapper for a 3D view, as shown in Figure 10.16. Once the obstructions are organized into different polyline groups, select the layers for each obstruction and save them as shapefiles, as shown in Figure 10.17. Repeat this process for each type of obstruction.

In QGIS, import each shapefile representing the different obstructions. Use the Model Designer in the Processing tab to streamline the approach to analyzing obstructions. Set the buffer to 0.0508 m (5.08 cm), or 2 inches, and choose to dissolve the results. For processing the polylines of the obstruction areas, first perform a "Lines to Polygons" operation, then an intersection between the new polygon and the sidewalk polygon. To determine how much of the gap percentage pertains to each obstruction, perform a difference operation between the intersection layer and the clipped point clouds layer, using the Model Designer again.

Run the model and choose an output file for the area. Create a new model to calibrate the buffer size of the point clouds, with the buffer size set to 3 inches for all layers. Repeat this process for the sidewalk data. To obtain the percentage of gap data, open the attribute tables of the newly buffered and dissolved layers, select all, and copy the data to the clipboard. Repeat for every obstruction type and add the attribute table to new sheets in an Excel document.

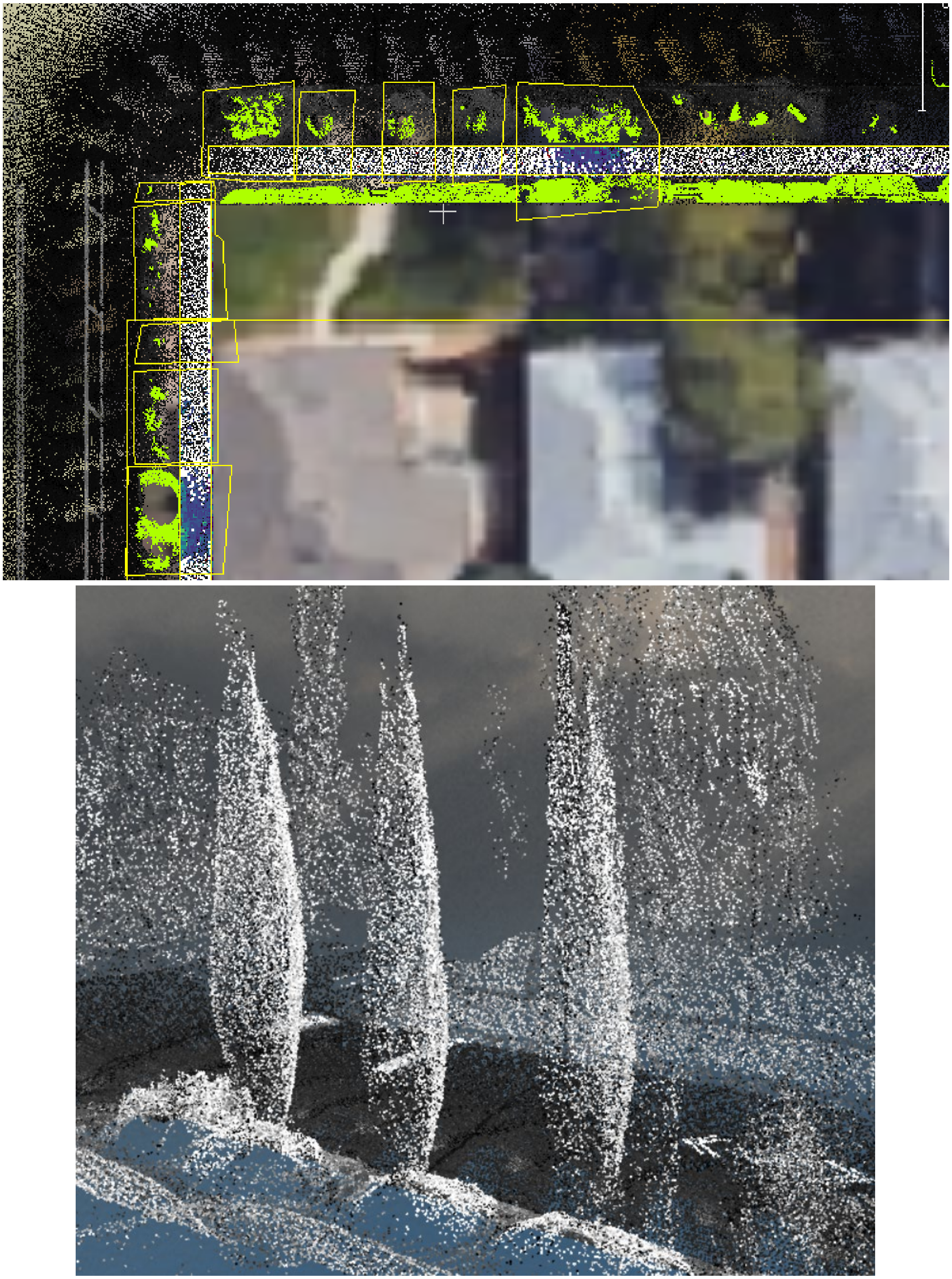


Figure 10.16 Double-Check Classification (3 dots in the top image are the 3 trees in the below image)

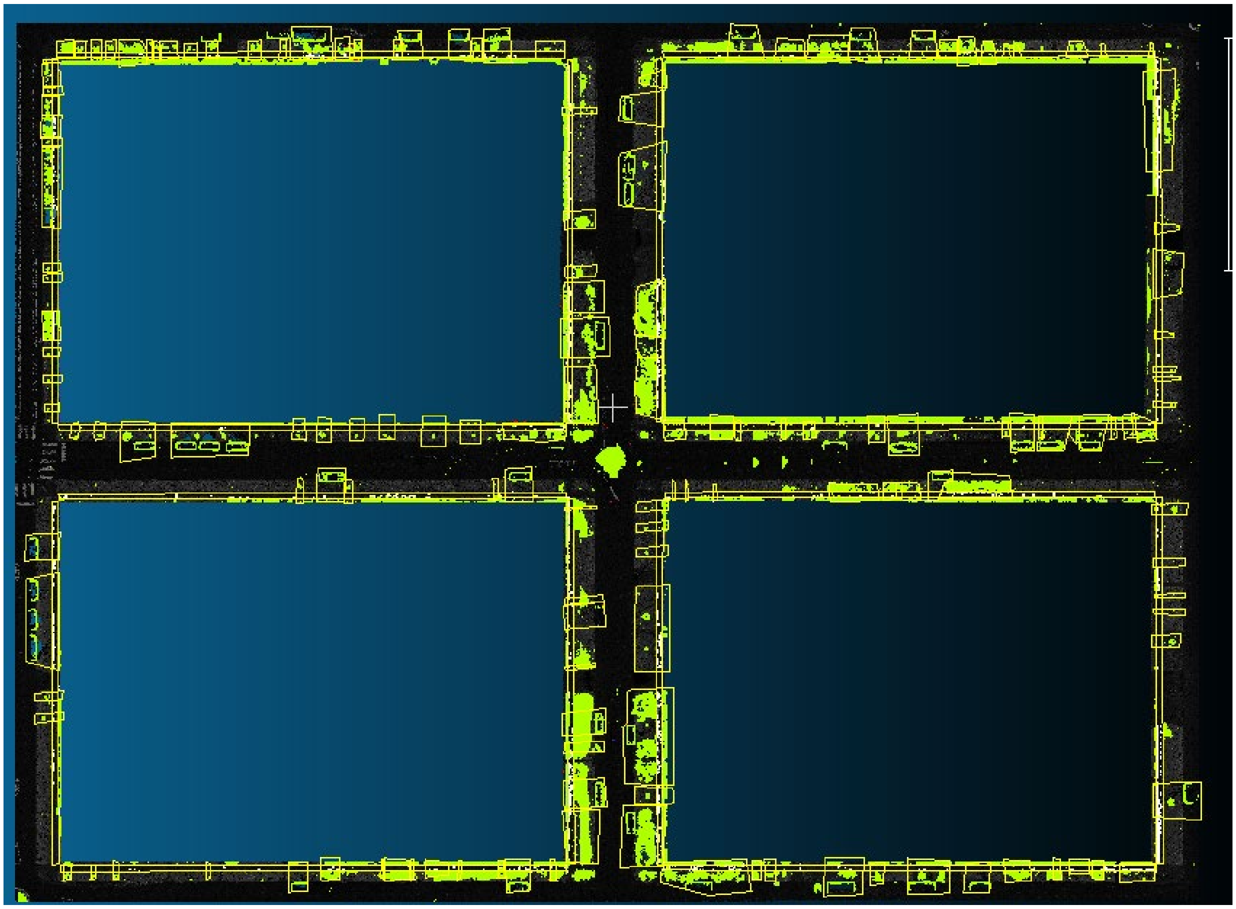


Figure 10.17 Obstruction Shapefile

Once the total area for each layer is determined as shown, create a table to calculate the percentage of total sidewalk area and the percentage in the obstruction gap data. Table 10.1 provides an example. The final table will show the total gap in data for each buffered layer, both for the backpack and the mobile LiDAR data, with an average calculated between the two buffers for the mobile LiDAR data.

10.6 Measuring Sidewalks for ADA Compliance

To measure sidewalks for ADA compliance, begin by assessing the sidewalk width, cross-slope, and running slope. First, open QGIS and search for “vector grid” in the toolbox. Select the “Create grid” tool under Vector Creation and generate a grid with dimensions of 50 x 50 feet. Save this grid as a file and click run. Once the grid is created, import it into Cloud Compare. Select one of the shapefiles and use the translate/rotation tool to manually align the grid with the point cloud data. Adjust using the tX and tY axes, ensuring tZ is unchecked.

Next, clip the grid to the sidewalk polygon area. Then, create an Excel sheet to organize the grid system on the point cloud data, which will be used to measure width values and cross-slope within the grid. In Cloud Compare, clone the grid twice and orient it with a spacing of 0.31 meters from the first grid, creating a 1-foot buffer to ensure accurate data collection, as shown in Figure 10.18.

Table 10.1 Calculating Data Gaps

The total gap in data for each buffered layer, both the backpack and the mobile LiDAR:

Data Type	percent of total sidewalk	Total Gaps (sq. m)
2-in-buffer-backpack	2.76	55.89
2-in-buffer-mobile	43.36	878.97
3-in-buffer-mobile	21.98	445.64
4-in-buffer-mobile	12.17	246.65
Total Area of sidewalks polygon		2083.20

Measurements representing the mobile LiDAR data with a 3-inch and 2-inch buffer:

	3in buffer			2in buffer			
Obstruction Type	Gap_Area	%of Total Sidewalk Data	%of Total Obstructions	Gap_Area	%of Total Sidewalk Data	%of Total Obstructions	Obstruction Type
Trees	39.98	1.92	8.97	81.85	3.93	9.31	Trees
Shrubs	33.48	1.61	7.51	51.16	2.46	5.82	Shrubs
Medium Veg.	75.97	3.65	17.05	98.09	4.71	11.16	Medium Veg.
Low Veg.	11.92	0.57	2.68	31.88	1.53	3.63	Low Veg.
Landscape	27.21	1.31	6.11	53.97	2.59	6.14	Landscape
Car and Veg.	39.06	1.88	8.77	54.51	2.62	6.20	Car and Veg.
Parked Cars	89.21	4.28	20.02	149.63	7.18	17.02	Parked Cars
Poles-Other	3.97	0.19	0.89	10.43	0.50	1.19	Poles-Other
Unclassified-Gap-Data	124.84	5.99	28.01	347.45	16.68	39.53	Unclassified-Gap-Data

Average between the two buffers for the mobile LiDAR data

AVG		
Gap_Area	%of Total Sidewalk Data	%of Total
60.91576333	2.924144495	9.141591
42.32052653	2.031515784	6.666561
87.02686318	4.177557811	14.1029
21.90123746	1.051326938	3.151087
40.59066506	1.948477098	6.12328
46.78832465	2.245983871	7.483734
119.4205598	5.732555147	18.52093
7.198542641	0.345552246	1.038598
143.9150704	6.91	33.77

If the sample of dots directly on the grid is insufficient, select two dots that fall within the buffer zone. Display only the isolated sidewalk data and zoom into the top-left section, as shown in Figure 9.19. The white dots represent mobile data, while the purple points represent backpack LiDAR data. With the backpack sidewalk data selected, zoom into the first grid, select the “Pick Points” tool, and choose the two points closest to the grid line that also reach the outer boundaries of the sidewalk polyline. Save the line selection. Repeat this process for the mobile-collected data and save the results in an Excel sheet.

In instances where the mobile-collected data are sparse in point clouds, choose two points where the change in x (or y for vertical sidewalks) is closest to zero. This method also applies to the sidewalk-collected data, shown as the red point cloud, with the white point cloud below representing a section of the mobile data, as seen in Figure 10.20.

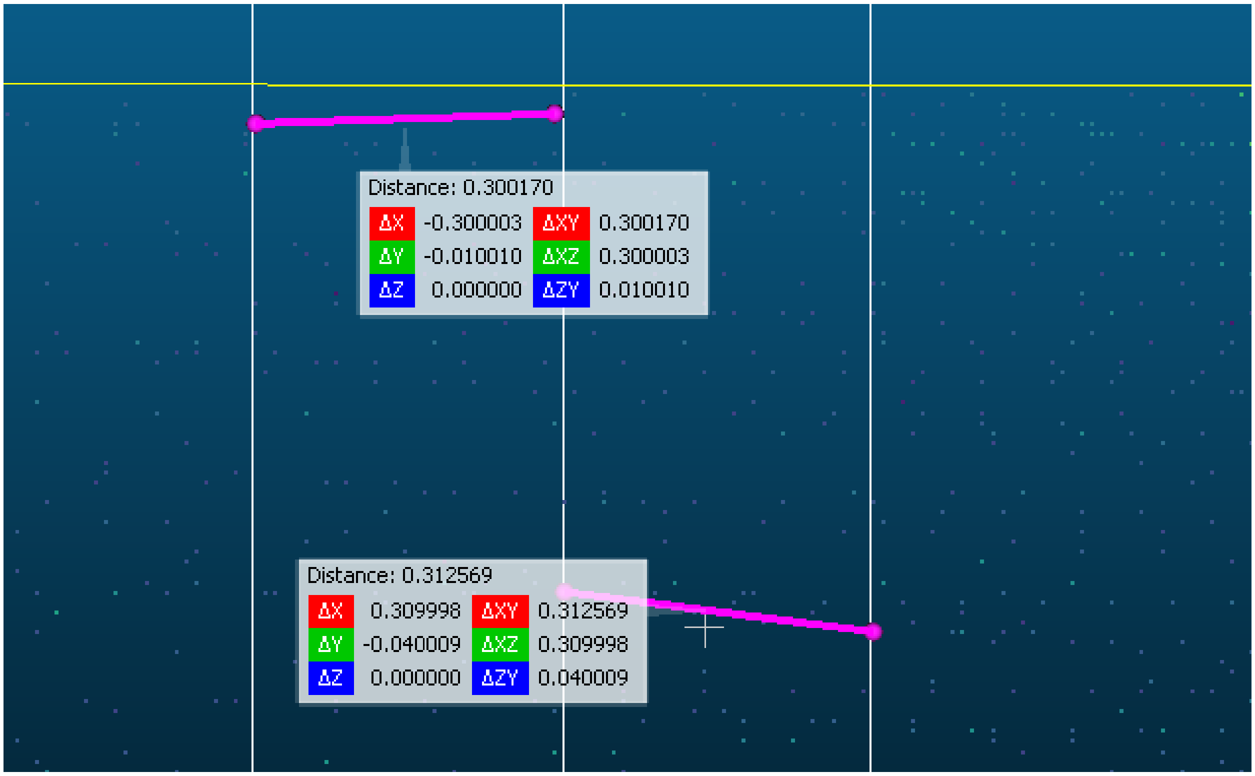


Figure 10.18 Buffering Cloud Compare Data

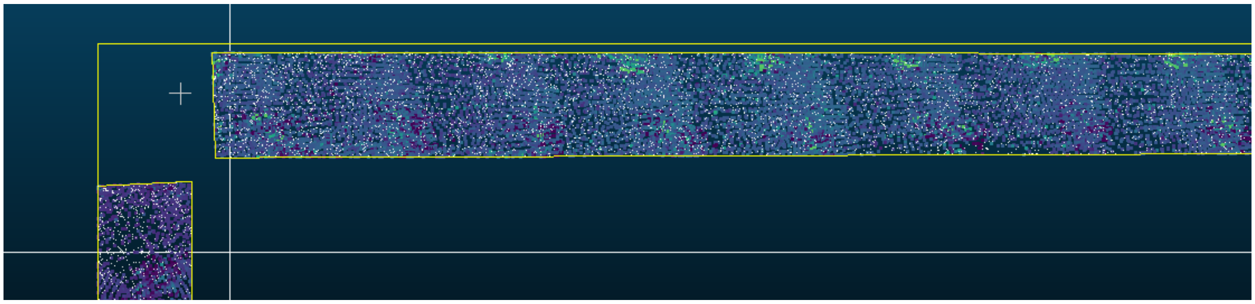


Figure 10.19 Isolating Sidewalk Data

To obtain the length of the gridded lines running across the sidewalk data, export the aligned grid from Cloud Compare and import it into QGIS. Add these data to an Excel sheet, with one sheet dedicated to sidewalk width and another for cross-slope. Tables can be created to display sidewalk width measurements, highlighting widths below 36 inches in red, as shown in Table 10.2, and to show the actual measurements of the grid lines intersecting sidewalk polygons, as measured using the “measure” tool in QGIS, as shown in Table 10.3. Additionally, create tables for the slopes measured in Cloud Compare, as shown in Table 10.4.

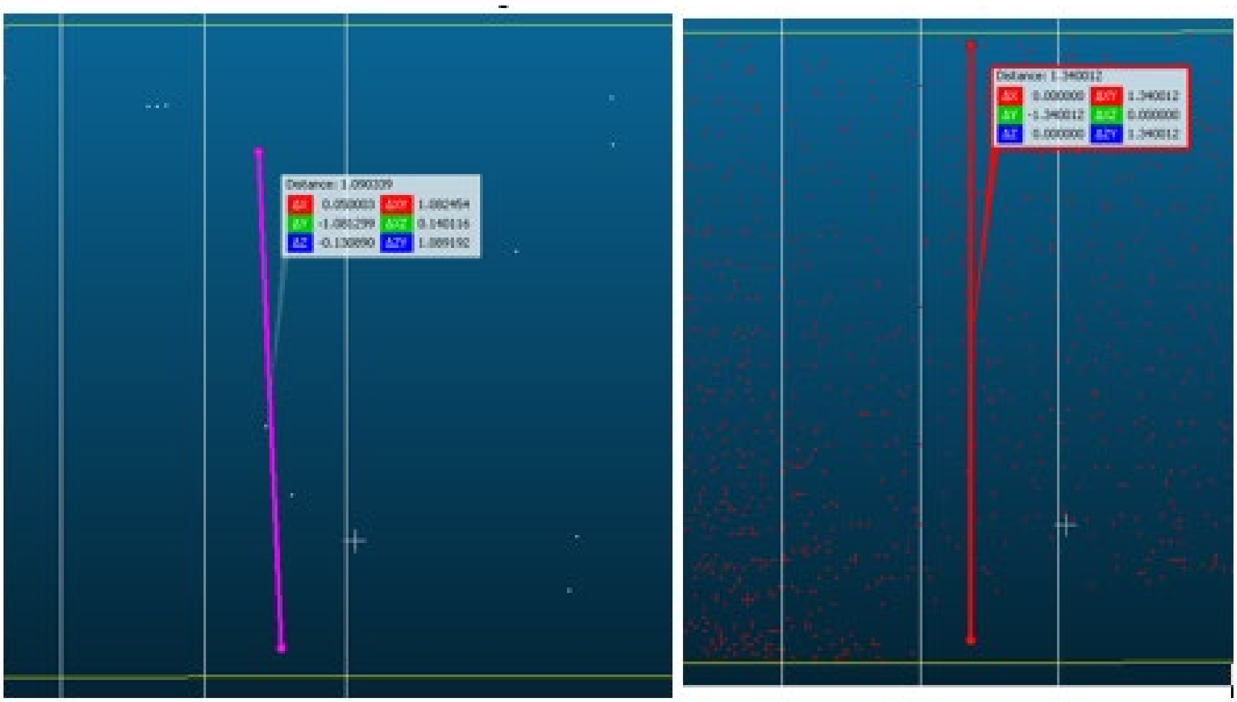


Figure 10.20 Representative LiDAR Point Cloud Data

To analyze the width data, use an R Studio program to determine the percentage discrepancy and standard deviation of the width measurements.

For analyzing curb ramps, the same procedure used for sidewalks is applied.

10.7 Attempting to Automate the Process via Python's PDAL

Attempts to automate the process using Python's PDAL were not successful in obtaining the desired results. As a result, these efforts have been documented in the appendices for reference. For details on counting cracks in the sidewalk, please refer to Appendix A. For information on the curb detection algorithm, refer to Appendix B.

Table 10.2 Sidewalk Width Measurements with <36" in Red

Backpack-collected Lidar																
53.5462	59.4489	55.9055	53.9512	51.1943	47.2512	44.883	48.8223		44.8911	46.8509	48.4324	50.0058	52.3676	51.1882	55.5134	47.2446
51.578							47.6397		45.6729							50.0023
50.5196							48.8217		48.8207							51.9927
48.8271							48.8201		50.3937							48.844
	53.9742	53.1688	49.2252	50.8	49.6373	47.6456				45.696	46.8935	48.0348	46.8538	49.6077	50.7933	
	47.2457	50.0018	51.5807	54.3452	55.9179	59.0578				56.3113	52.7564	54.7315	54.3324	53.1513	52.3682	
49.2268							50.7902		55.9083							51.5777
49.2205							53.1522		55.1199							49.2142
50.7905							49.2142		54.3338							48.0316
51.1812	54.3877	54.7258	54.7275	53.9397	54.7258	54.7244	55.9124		53.504	55.9235	54.3424	53.5491	51.97	46.5134	48.8268	44.4901
Mobile-collected Lidar																
53.072	59.4489	56.2599	52.587	45.9464	47.6327	42.5226	44.379		43.8618	46.3409	50.3276	47.7784	32.5352	19.7828	54.9831	47.4153
50.2134							48.7178		41.966							48.4756
21.5354							47.2463		48.5442							50.5667
46.2859							45.4797		47.0382							48.1859
	52.1794	46.5788	50.5345	45.975	47.9992	46.8018				46.3964	45.2928	40.8644	48.5351	48.5068	50.3859	
	40.2542	45.8629	50.8132	53.5565	53.6716	58.3092				50.7672	42.9268	54.3472	48.728	43.9846	51.1401	
46.9639							52.0696		55.386							37.4665
42.4497							51.8453		49.9596							50.3888
50.1644							16.7567		54.2571							47.0164
49.7962	53.7968	46.2966	49.9272	53.125	53.9378	52.2905	53.9247		54.132	53.5089	53.6435	51.3005	48.993	34.704	49.1373	46.2661

Table 10.3 Actual Measurements of Grid Lines Intersecting Polygons

Actual length of sidewalk																
53.9764	60.3544	57.441	54.3701	51.5748	48.6614	45.5906	49.1339		45.3544	47.2047	49.0551	50.7874	52.5197	54.3701	56.1024	48.8583
52.7166							49.1733		47.2047							50.7874
51.4567							49.1339		48.9764							52.5197
50.1181							49.1339		50.8268							54.2914
	55.1575	53.8189	52.5197	51.1811	49.8425	48.5433				46.811	47.5985	48.6614	49.6063	50.3937	51.2992	
	47.874	50.2362	52.6378	54.8819	57.0079	59.252				56.7323	55.9449	55.2756	54.6063	53.9764	53.4252	
49.4488							52.3229		55.6693							53.1103
50.1969							53.7008		55.1575							50.9843
50.8268							55.0394		54.4095							48.9764
51.4961	55.0394	55.1575	55.0394	55.1575	55.1575	55.1575	56.3386		53.8189	56.3386	55.0394	53.8189	52.5197	51.063	49.8425	47.0079

Table 10.4 Slopes for Each Distance Measured in Cloud Compare

Backpack-collected Lidar					
	y-grid	1st column of vertical roads	2nd column of vertical roads	3rd column of vertical roads	4th column of vertical roads
x-grid	1	[23:40:55] [Picked]- ΔX: 1.360001ΔY: -0.010010ΔZ: 0.009979	[00:39:43] [Picked]- ΔX: 1.240005ΔY: -0.010010ΔZ: - 0.010010	[02:35:39] [Picked]- ΔX: 1.140015ΔY: -0.009979ΔZ: 0.019989	[02:58:52] [Picked]- ΔX: 1.200012ΔY: 0.000000ΔZ: 0.000000
	2	N/A	N/A	N/A	N/A
	3	[23:49:19] [Picked]- ΔX: 1.310005ΔY: -0.010010ΔZ: 0.009979 [23:49:19] [Picked]- ΔXY: 1.310043ΔXZ: 1.310043ΔZY:	[00:44:17] [Picked]- ΔX: 1.210007ΔY: 0.000000ΔZ: - 0.010010	[02:39:31] [Picked]- ΔX: -1.160004ΔY: -0.010010ΔZ: - 0.009979	[03:01:49] [Picked]- ΔX: 1.270020ΔY: 0.000000ΔZ: - 0.010010
	4	N/A	N/A	N/A	N/A
	5	[23:52:07] [Picked]- ΔX: 1.279999ΔY: -0.010010ΔZ: - 0.089996	[00:46:17] [Picked]- ΔX: 1.239990ΔY: 0.009979ΔZ: - 0.009979	[02:40:52] [Picked]- ΔX: 1.240005ΔY: -0.009979ΔZ: 0.000000	[03:05:22] [Picked]- ΔX: -1.320007ΔY: 0.000000ΔZ: 0.040009
	6	N/A	N/A	N/A	N/A
	7	[23:55:01] [Picked]- ΔX: 1.240005ΔY: 0.020020ΔZ: 0.010010 [23:55:01] [Picked]- ΔXY: 1.240167ΔXZ: 1.240046ΔZY:	[00:50:45] [Picked]- ΔX: 1.239990ΔY: 0.000000ΔZ: - 0.010010	[02:43:48] [Picked]- ΔX: 1.279999ΔY: 0.000000ΔZ: 0.000000	[03:10:04] [Picked]- ΔX: 1.239990ΔY: 0.000000ΔZ: - 0.040009
	8	N/A	N/A	N/A	N/A
	9	0	0	0	0
	10	N/A	N/A	N/A	N/A
	11	[00:01:52] [Picked]- ΔX: 1.250000ΔY: 0.000000ΔZ: 0.029999	[00:52:32] [Picked]- ΔX: 1.289993ΔY: -0.009995ΔZ: - 0.010010	[02:45:22] [Picked]- ΔX: -1.419998ΔY: 0.009995ΔZ: - 0.010010	[03:11:40] [Picked]- ΔX: 1.309998ΔY: -0.009995ΔZ: - 0.010010
	12	N/A	N/A	N/A	N/A
	13	[00:03:34] [Picked]- ΔX: 1.250000ΔY: -0.020004ΔZ: 0.010010	[00:58:27] [Picked]- ΔX: 1.349991ΔY: -0.010010ΔZ: - 0.010010	[02:49:22] [Picked]- ΔX: 1.400009ΔY: 0.000000ΔZ: 0.009979	[03:15:52] [Picked]- ΔX: 1.250000ΔY: 0.000000ΔZ: - 0.010010
	14	N/A	N/A	N/A	N/A
	15	[00:07:18] [Picked]- ΔX: 1.290001ΔY: -0.009995ΔZ: 0.010010 [00:07:18] [Picked]- ΔXY: 1.290040ΔXZ: 1.290040ΔZY:	[00:59:55] [Picked]- ΔX: 1.250000ΔY: 0.000000ΔZ: - 0.010010	[02:50:53] [Picked]- ΔX: 1.380005ΔY: -0.010010ΔZ: 0.010010 [02:50:53] [Picked]- ΔXY: 1.380041ΔXZ: 1.380041ΔZY:	[03:16:53] [Picked]- ΔX: 1.220001ΔY: 0.000000ΔZ: 0.000000
	16	N/A	N/A	N/A	N/A
	17	[00:12:54] [Picked]- ΔX: 1.300003ΔY: 0.000000ΔZ: 0.000000	[01:14:40] [Picked]- ΔX: 1.419998ΔY: 0.010002ΔZ: - 0.019989	[02:56:24] [Picked]- ΔX: 1.350006ΔY: 0.000000ΔZ: 0.009979	[03:20:03] [Picked]- ΔX: 1.130005ΔY: 0.000000ΔZ: - 0.009979

Mobile-collected Lidar			% error in human is from not able to get a y=0, also from data		
	y-grid				
x-grid	0				
	1	[23:43:16] [Picked]- ΔX: 1.347298ΔY: -0.044128ΔZ: 0.004303	[00:40:56] [Picked]- ΔX: 1.127106ΔY: 0.003693ΔZ: - 0.015991	[02:36:39] [Picked]- ΔX: 1.113998ΔY: -0.006592ΔZ: - 0.012604	[02:59:59] [Picked]- ΔX: 1.204315ΔY: 0.007202ΔZ: - 0.005402
	2	N/A	N/A	N/A	N/A
	3	[23:46:45] [Picked]- ΔX: 1.275398ΔY: 0.006805ΔZ: - 0.002991	[00:43:27] [Picked]- ΔX: 1.236801ΔY: -0.022705ΔZ: - 0.032318	[02:38:09] [Picked]- ΔX: 1.065201ΔY: -0.037994ΔZ: - 0.011017	[03:02:38] [Picked]- ΔX: 1.272797ΔY: 0.002686ΔZ: - 0.028900
	4	N/A	N/A	N/A	N/A
	5	[23:50:17] [Picked]- ΔX: 0.546898ΔY: 0.010498ΔZ: - 0.000793	[00:47:14] [Picked]- ΔX: 1.199402ΔY: -0.023102ΔZ: - 0.032196	[02:41:49] [Picked]- ΔX: 1.232895ΔY: -0.000519ΔZ: - 0.017700	[03:04:29] [Picked]- ΔX: 1.282806ΔY: 0.017700ΔZ: - 0.061310
	6	N/A	N/A	N/A	N/A
	7	[23:56:01] [Picked]- ΔX: -1.175598ΔY: 0.012207ΔZ: - 0.000214	[00:49:00] [Picked]- ΔX: 1.155106ΔY: 0.007599ΔZ: - 0.011200	[02:42:54] [Picked]- ΔX: 1.194702ΔY: -0.010803ΔZ: - 0.006683	[03:07:05] [Picked]- ΔX: 1.216217ΔY: -0.011322ΔZ: - 0.136627
	8	N/A	N/A	N/A	N/A
	9	0	0	0	0
	10	N/A	N/A	N/A	N/A
	11	[00:00:25] [Picked]- ΔX: 1.191597ΔY: -0.032211ΔZ: 0.045013 [00:00:25] [Picked]- ΔXY: 1.192032ΔXZ: 1.192447ΔZY:	[00:55:21] [Picked]- ΔX: 1.322205ΔY: -0.020004ΔZ: - 0.023712	[02:46:07] [Picked]- ΔX: 1.406799ΔY: 0.002396ΔZ: - 0.002197	[03:13:31] [Picked]- ΔX: 0.951508ΔY: -0.016006ΔZ: - 0.003571
	12	N/A	N/A	N/A	N/A
	13	[00:05:30] [Picked]- ΔX: -1.078201ΔY: 0.004608ΔZ: - 0.004578	[00:57:02] [Picked]- ΔX: -1.316711ΔY: 0.018906ΔZ: 0.007507	[02:48:26] [Picked]- ΔX: -1.268906ΔY: -0.012909ΔZ: - 0.001617	[03:14:47] [Picked]- ΔX: 1.279694ΔY: -0.015198ΔZ: - 0.015381
	14	N/A	N/A	N/A	N/A
	15	[00:06:25] [Picked]- ΔX: 1.273994ΔY: -0.020706ΔZ: 0.005890	[01:01:12] [Picked]- ΔX: -0.424713ΔY: -0.020996ΔZ: 0.018188	[02:53:04] [Picked]- ΔX: 1.378098ΔY: -0.007599ΔZ: 0.005615	[03:17:32] [Picked]- ΔX: 1.194183ΔY: 0.006195ΔZ: 0.006317 [03:17:32] [Picked]- ΔXY: 1.194199ΔXZ: 1.194200ΔZY:
	16	N/A	N/A	N/A	N/A
	17	[00:14:04] [Picked]- ΔX: 1.264603ΔY: -0.000305ΔZ: - 0.023590	[01:13:48] [Picked]- ΔX: -1.369507ΔY: -0.019203ΔZ: 0.010986	[02:54:28] [Picked]- ΔX: 1.374893ΔY: -0.007500ΔZ: 0.010101	[03:18:57] [Picked]- ΔX: 1.175110ΔY: -0.010300ΔZ: 0.002716 [03:18:57] [Picked]- ΔXY: 1.175155ΔXZ: 1.175113ΔZY:

11. RESULTS

There are two parts to the results: 1) evaluating the data gaps for both point clouds caused by obstructions, and 2) measuring the ADA compliance of the sidewalks and the curb ramps.

11.1 Data Gaps

There is a substantial number of sidewalk gaps in the mobile LiDAR versus the backpack LiDAR, and this is attributed to obstructions between the vehicle and the sidewalk. When the point clouds are vectorized into point shapefiles, they are given a specific diameter in buffer for each shapefile. When placing a 2-inch buffer on the backpack point cloud, it showed 2.76% in sidewalk gap data, whereas the mobile LiDAR had 43.36% of gaps with a 2-inch buffer. A 3-inch buffer on the mobile point cloud data shows 21.98% in data gaps while the 4-inch buffered mobile data has 12.17% of data gaps in the sidewalk. Essentially, the percentage of gaps in the mobile data reduces by half as the size of the buffer increases by increments of 1 inch. For this reason, the average between the 3-inch buffer and the 2-inch buffer was examined for the mobile LiDAR data, where a 2-inch buffer was analyzed for the backpack LiDAR data.

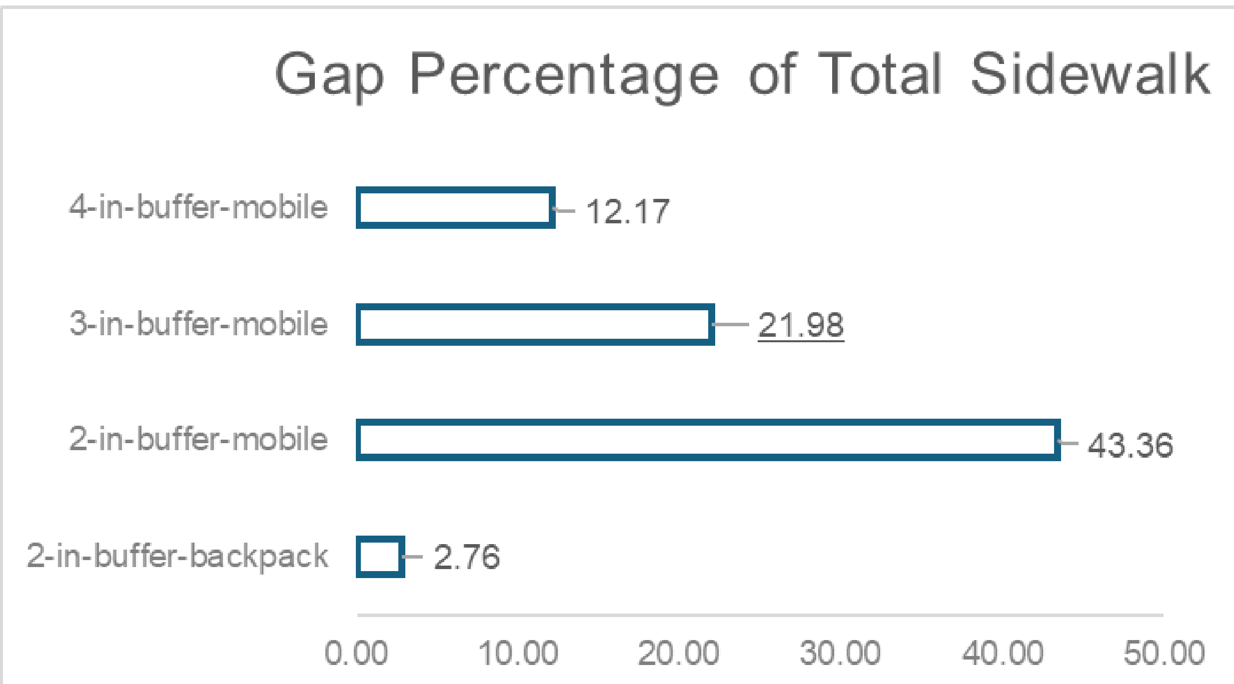


Figure 11.1 Total Percentage of Gaps within Each Layer, Given Various Buffer Sizes

There are several obstructions that cause gaps in the LiDAR sidewalk data:

- medium vegetation, including bushes
- a combination of parked vehicles and vegetation
- tree trunks and smaller trees
- shrubs
- landscape such as hills, rocks, or planters between the road and the sidewalk
- low vegetation, such as annuals and garden beds
- poles and street signs

The following graphs in Figure 11.2 show the effects of different obstructions in the mobile LiDAR data:

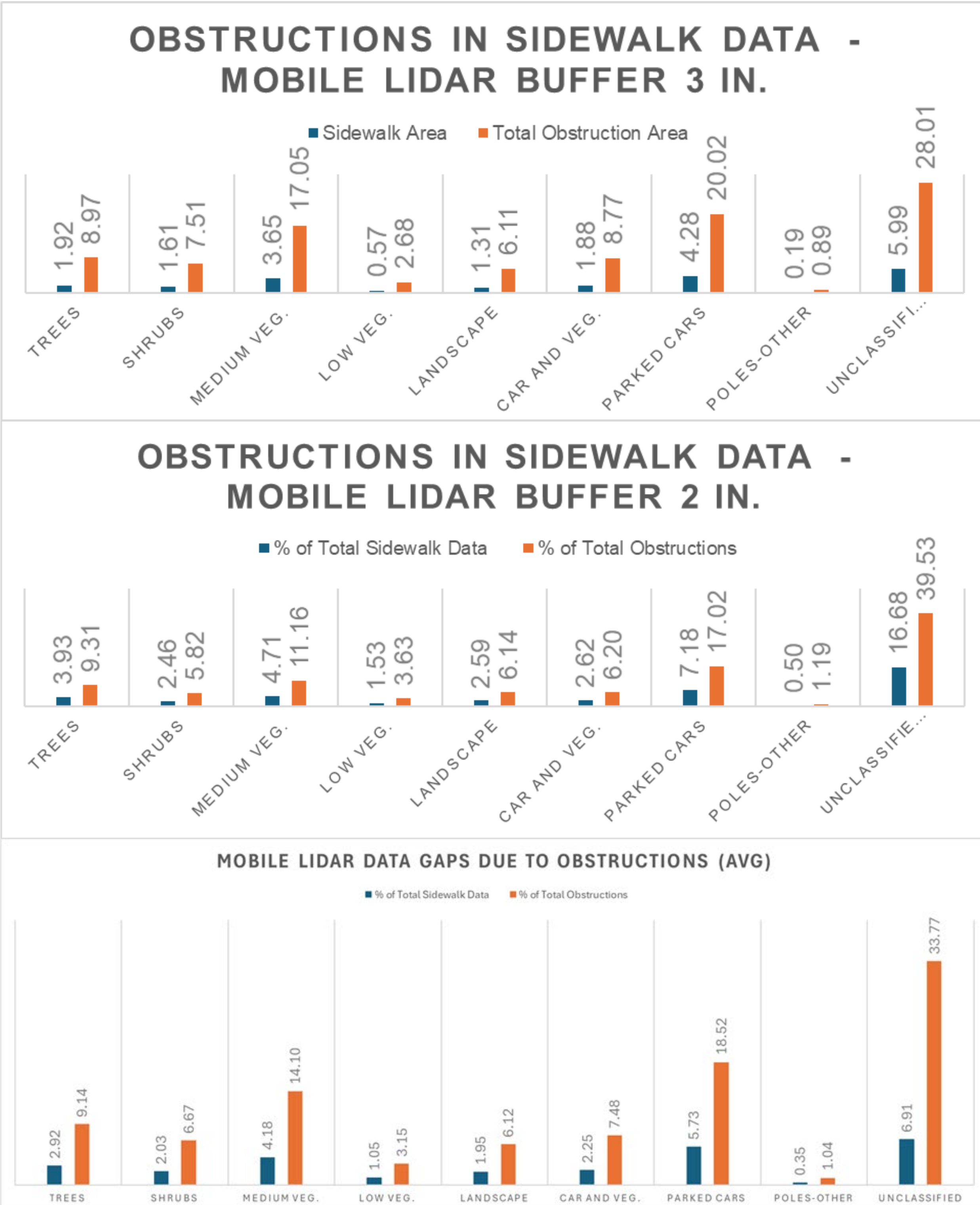


Figure 11.2 Effects of Various Obstructions

Figure 11.3 shows the average, and it combines the categories into a total of four.

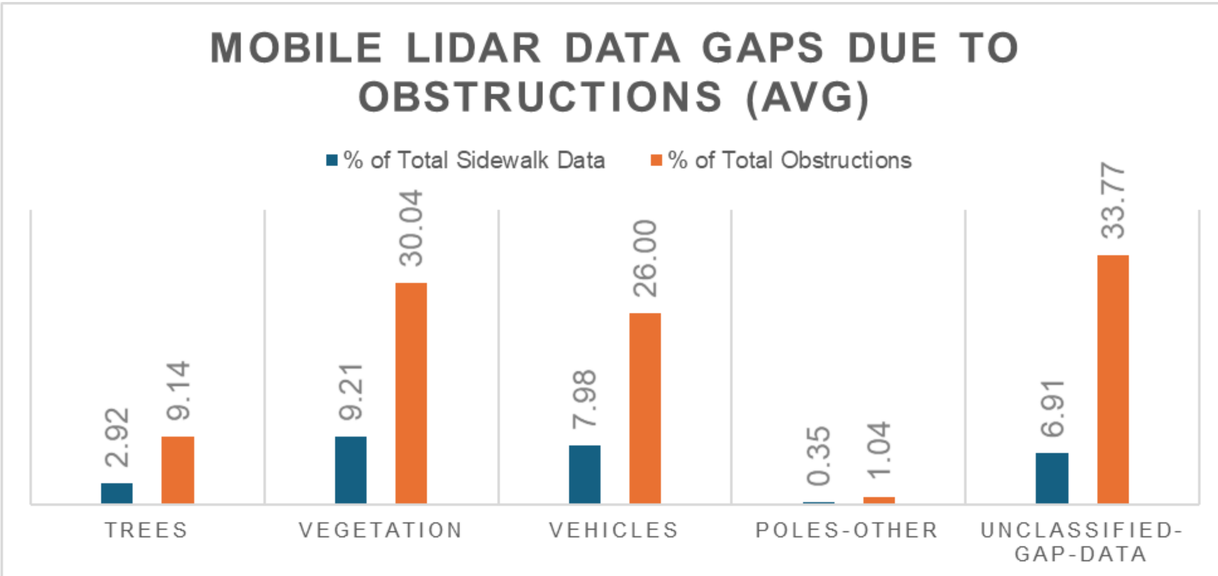


Figure 11.3 Average Gaps Due to Obstructions

Figure 11.4 shows there is 2.68% of data gaps in the backpack-collected LiDAR data when using a 2-inch buffer. To obtain which portion of the total gap is attributed to spaces in the point cloud, 2.68% was multiplied by the percentage of unclassified data within the mobile LiDAR data, which is 33.77%. So roughly 1/3 of the total gaps in backpack LiDAR data was attributed to unclassified data, while roughly 2/3 of the total gap data was due to low vegetation looming over the sidewalk.

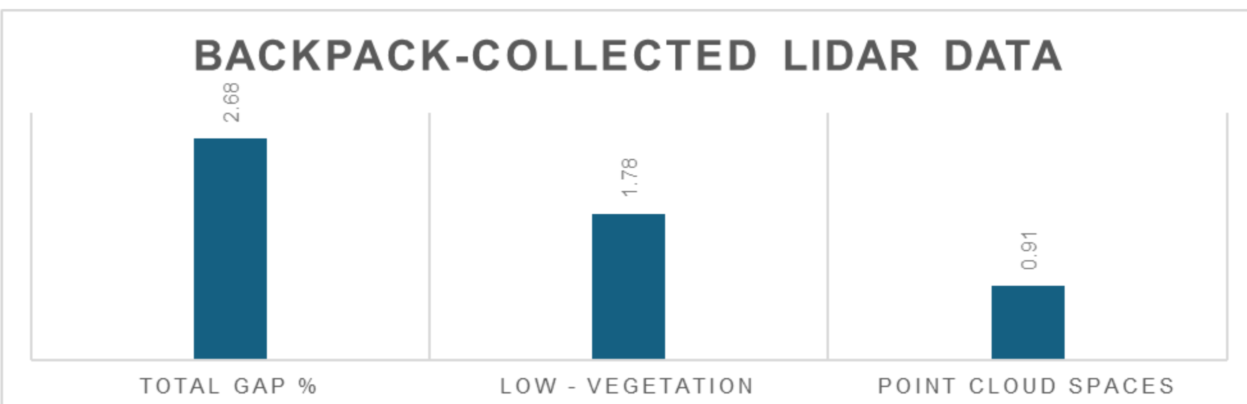


Figure 11.4 Backpack-Collected LiDAR Gaps with 2-inch Buffer

11.2 ADA Compliance Data for Sidewalk Width

Both sets of LiDAR data can extract the width of the sidewalk, but the mobile data cannot measure the width where obstructions exist.

The following is the average percentage discrepancy for measuring the sidewalk width:

- Backpack LiDAR: 1.9017% discrepancy
- Mobile LiDAR: 8.7656% discrepancy

When looking at the mobile LiDAR data, the sidewalk widths under 36 inches range between 30% and 70% discrepancy, as shown in Table 11.1.

Table 11.1 Sidewalk Width Discrepancies

backpack	mobile	actual	% discrepancy-back	% discrepancy-mobile
50.51963	21.53541	51.45672	1.821117062	58.14850803
49.2142	16.75674	55.0394	10.58369099	69.55500715
52.36763	32.53521	52.51971	0.28958021	38.05142429
51.18822	19.78285	54.37011	5.852280956	63.61448226
46.51341	34.70396	51.06302	8.909791827	32.03700848

Paired samples t-tests were conducted to compare the mean measurements of "backpack" and "mobile" with the actual values. The mobile data have a p-value of 0.003, while the backpack data have a p-value of 0.0003. This shows that the backpack-collected data are much more statically significant than the mobile LiDAR data.

These results suggest that both "back" and "mobile" measurements exhibit a systematic bias toward lower values compared with the actual measurements. Therefore, the "backpack" measurements appear to be closer to the actual values compared with the "mobile" measurements.

11.3 ADA Compliance Data for Sidewalk Cross-Slope

Most of the sidewalk segments that were measured for cross-slopes and running-slopes adhered to ADA compliance. Using Mobile LiDAR data, it is possible to obtain cross-slope data of the sidewalk and to analyze them via Cloud Compare or a similar program. Based on the data tables below, most of segments adhered to ADA compliance for the cross-slope. Table 11.2 depicts cross-slope data collected by the backpack LiDAR while Table 11.3 shows data collected from the mobile LiDAR.

Table 11.2 Cross-slope Data Collected by Backpack LiDAR

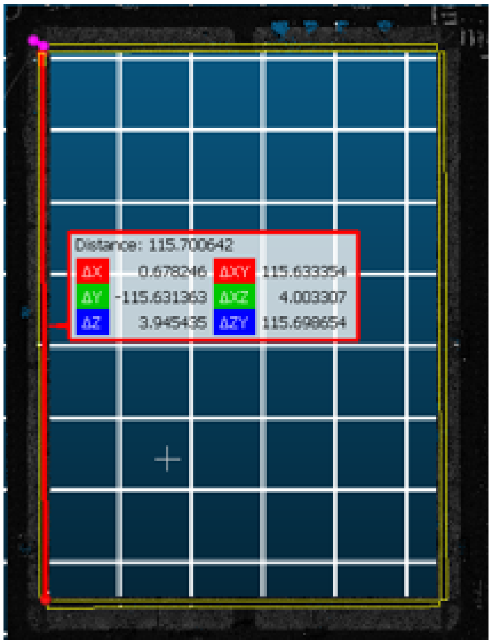
ΔX	ΔZ	`	Cross-Slope Ratio
1.360074	0.009979	0.007337101	1:0.01
1.310081	0.009979	0.007617086	1:0.01
1.283198	0.089996	0.070134149	7:1
1.240207	0.01001	0.008071233	1:0.01
1.25036	0.029999	0.02399229	3:1
1.2502	0.01001	0.008006719	1:0.01
1.290078	0.01001	0.007759221	1:0.01
1.300003	0	0	0:1
1.240086	0.01001	0.008072021	1:0.01
1.210048	0.01001	0.008272399	1:0.01
1.240071	0.009979	0.00804712	1:0.01

Table 11.3 Cross-slope Data Collected by Mobile LiDAR

ΔX	ΔZ	Cross-Slope (ΔZ/ΔX)	Cross-Slope Ratio
1.348027	0.004303	0.003192073	1:0.003
1.27542	0.002991	0.00234511	1:0.002
0.546999	0.000793	0.001449728	1:0.001
1.175662	0.000214	0.000182025	1:0
1.192882	0.045013	0.037734663	38:1
1.078221	0.004578	0.004245883	1:0.004
1.274176	0.00589	0.004622595	1:0.005
1.264823	0.02359	0.018650831	1:0.019
1.127225	0.015991	0.014186165	1:0.014

11.4 ADA Compliance for Sidewalk Slope

The obstructions do not cause difficulties in obtaining the running slope of the sidewalk, and any data gaps can be interpolated for this measurement. For any sidewalk segment, run the distance from one side to the next using "Pick Points," then divide that distance by the change in z, as shown in Figure 11.5.



ΔZ = 3.945345 m
ΔX=115.700642 m

Ratio is ΔZ/ΔX = 3.945345/115.700642
Ratio is 3.945345:115.700642

Ratio: 1: 0.034

Figure 11.5 Sidewalk Running Slope

11.5 ADA Compliance for Curb Ramps

Curb ramp features can be easily analyzed in both point clouds because they are located on the corner of the intersections where there are minimal obstructions. Due to its location, a car driving through an intersection has the possibility of scanning a curb ramp with a 270-degree view around the corner, thus circumventing any obstructions. The widths, cross slopes, running slopes, and counter slopes are analyzed in the same methodology as the sidewalks.

The curb ramp lips and other lips greater than ¼ inches can be detected, but it is difficult to analyze in Cloud Compare when the LiDAR data do not have RGB associated with them. The counter slopes from the roads can be measured as well, but they are difficult to visualize without RGB imagery. The images in Figure 11.6 show how the curb ramps look in Cloud Compare when zoomed in, and zoomed out. Figure 11.7 depicts the curb ramp width measurement.

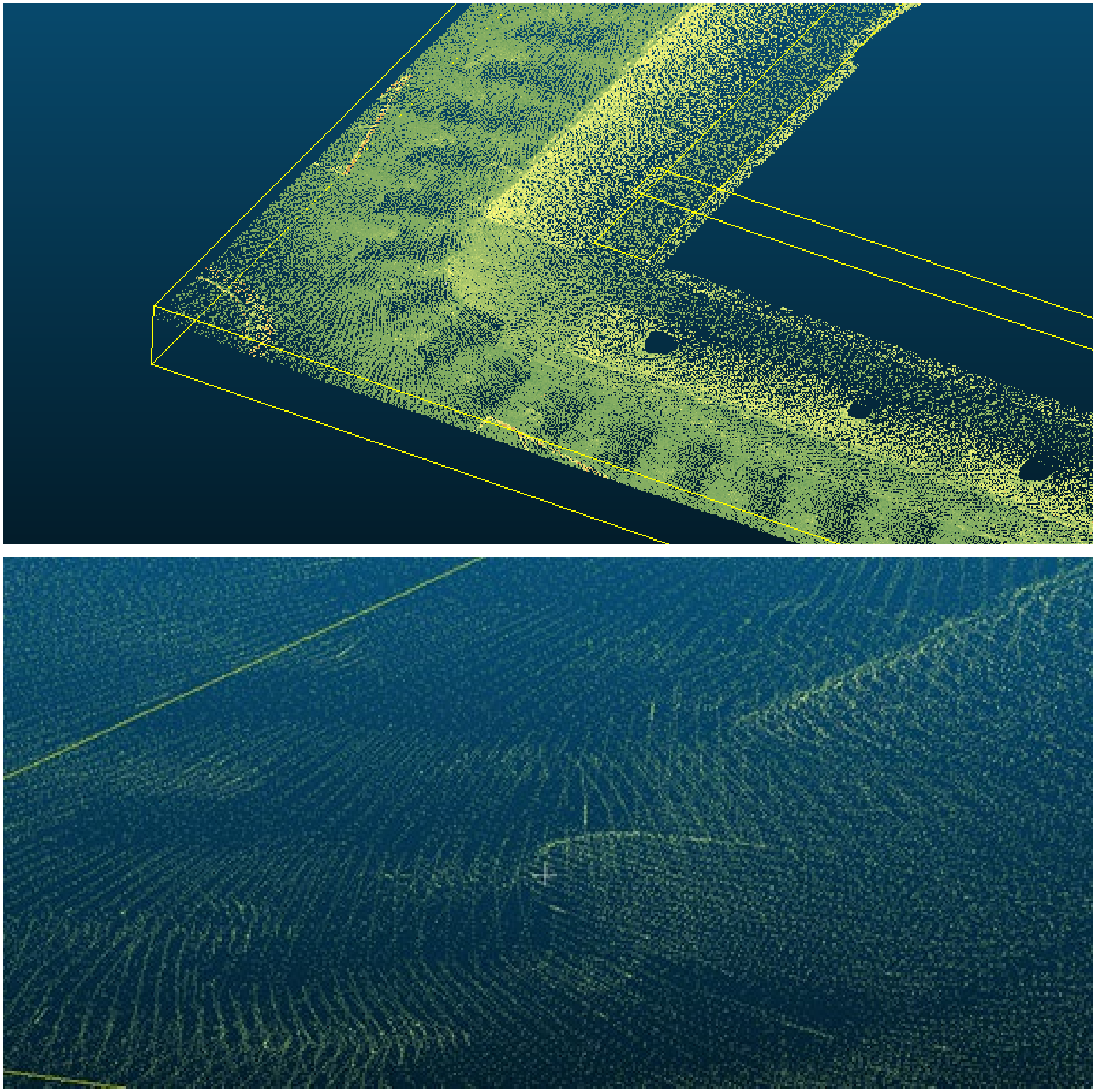


Figure 11.6 Curb Ramps in Cloud Compare

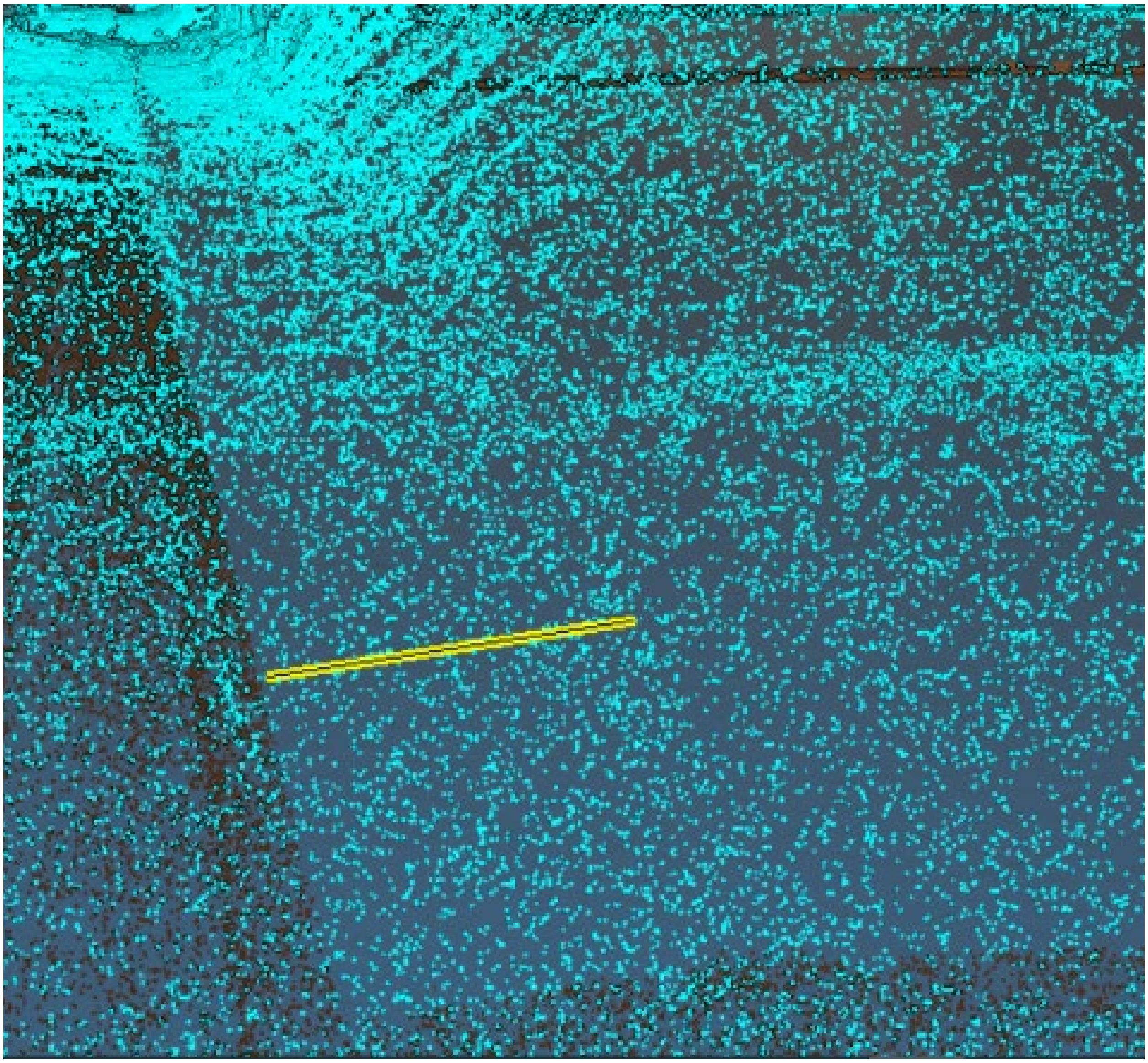


Figure 11.7 Curb Ramp Width Measurement in Cloud Compare

To obtain the running slope of the curb ramp, simply use the “Pick Points” tool to select two points, as shown in Figure 11.8, and calculate the running slope:

- Distance = 4.079687
- Change in Z = 0.07598

$$\text{Ratio} = \frac{\text{Change in Z}}{\text{Distance}} = \frac{0.07598}{4.079687} = 1:0.018$$

Figure 11.8 Curb Ramp Running Slope Measurement in Cloud Compare

12. CONCLUSIONS

The study demonstrates that it is feasible to obtain ADA compliance data for sidewalks and curb ramps using a mobile LiDAR sensor. However, the primary challenge lies in the physical obstructions between the curb and the LiDAR sensor, particularly in neighborhoods where vegetation and parked vehicles account for most of these obstacles. In this case, vegetation and parked vehicles combined contributed to 16.12% of the total sidewalk data and 56% of the total gap in mobile LiDAR data. More specifically, vegetation caused 30% of the gaps, while parked vehicles were responsible for 26%. Additionally, 33.77% of the unclassified gap data resulted from small gaps between points within the point cloud and misalignment issues. Other factors such as trees, which account for 9.14% of the gaps due to their trunks raising the landscape, and minor contributions from traffic signs and electrical poles, which accounted for 1.04%, were also noted.

In contrast, the backpack LiDAR data showed a much lower percentage of gaps within their sidewalk data, with a total of 2.76%. Of this, 0.91% was due to unclassified spaces between point clouds, and 1.78% was attributed to low vegetation overhanging the sidewalks. Despite the 32.67% gap in mobile LiDAR data, the measurements for sidewalk width, cross-slope, and running slope were still achievable. This percentage gap represents the average total gap percentage of the 2-inch and 3-inch buffered mobile data. The point clouds also allowed for the measurement of ¼-inch lips and counter-slopes related to curb ramps.

The study also found that the distance between parked cars and the sidewalk significantly impacts the data gap, with less obstruction when cars are farther from the sidewalk. A single parked car causes minimal obstruction, but a series of parked cars can create larger gaps as the LiDAR sensor struggles to capture the sidewalk behind them. The neighborhood in question had a considerable distance between the sidewalk and parked cars, with elevated landscapes further complicating data collection. The proximity of the road or vegetation to the sidewalk also played a role in the level of obstruction, with varying effects depending on the specific road. These findings suggest that this method may be less effective in densely populated metropolitan areas where obstructions are likely to be more prevalent. The number and type of obstructions can also vary by season, as seen in areas like Denver where winter foliage is less dense.

During the data processing phase in Cloud Compare, several issues arose. For instance, when creating polylines, adjusting the Z-axis angle could alter the selection, and the elevation at which the polylines were created could introduce errors in isolating the sidewalk if the view was not directly from the top. Additionally, attempts to automate the process using Python's PDAL faced challenges. A gap count program was developed to detect sidewalk cracks deeper than a quarter inch, with changes in X or Y greater than 6 inches. While the program successfully classified points related to gaps, it did not accurately identify sidewalk cracks but rather gaps in the data themselves. The curb detection algorithm created during the study was able to identify curb points but faced issues with scaling and alignment to the actual data. Despite these challenges, there is potential for using the curb detection algorithm, although resolving scaling issues remains crucial for its successful implementation.

13. REFERENCES

Ai, C., & Tsai, Y. (2016). "Automated Sidewalk Assessment Method for Americans with Disabilities Act Compliance Using Three-Dimensional Mobile LiDAR." *Transportation Research Record: Journal of the Transportation Research Board*, 2542(1), 25–32. https://doi.org/10.3141/2542-04

American Fact Finder 2010 Census Summary File 2 PCT3. (n.d.). http://www.factfinder2.census.gov
Cameron, C. (2013). "IPhone LiDAR Applications Utilized For Improving Pedestrian Infrastructure Data Collection Efforts For ADA Compliance." Available at: UC Denver, Civil Engineering.

Apellániz, J. L., García, M., Aranjuelo, N., Barandiarán, J., & Nieto, M. (2023). "LiDAR-based curb detection for ground truth annotation in Automated Driving Validation." 2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC). https://doi.org/10.1109/itsc57777.2023.10422558

Awrangjeb, M. (2016a). "Using point cloud data to identify, trace, and regularize the outlines of buildings." *International Journal of Remote Sensing*, 37(3), 551–579. https://doi.org/10.1080/01431161.2015.1131868

Balado, J., Díaz-Vilariño, L., Arias, P., & González-Jorge, H. (2018). "Automatic classification of urban ground elements from mobile laser scanning data." *Automation in Construction*, 86, 226–239. https://doi.org/10.1016/j.autcon.2017.09.004

Hou, Q., & Ai, C. (2020). "A network-level sidewalk inventory method using mobile LiDAR and deep learning." *Transportation Research Part C: Emerging Technologies*, 119, 102772. https://doi.org/10.1016/j.trc.2020.102772

Huang, J., Choudhury, P. K., Yin, S., & Zhu, L. (2021). "Real-Time Road Curb and Lane Detection for Autonomous Driving Using LiDAR Point Clouds." *IEEE Access*, 9, 144940–144951. https://doi.org/10.1109/access.2021.3120741

Li, H., Cebe, J., Khoeini, S., Xu, Y. "Ann," Dyess, C., & Guensler, R. (2018). "A Semi-Automated Method to Generate GIS-Based Sidewalk Networks for Asset Management and Pedestrian Accessibility Assessment." *Transportation Research Record: Journal of the Transportation Research Board*, 2672(44), 1–9. https://doi.org/10.1177/0361198118757981

Rhee, J., & Seo, J. (2019). "Low-cost curb detection and localization system using multiple ultrasonic sensors." *Sensors*, 19(6), 1389. https://doi.org/10.3390/s19061389

Tsai, Y. (James), Ai, C., Wang, Z., & Pitts, E. (2013). "Mobile Cross-Slope Measurement Method Using LiDAR Technology." *Transportation Research Record: Journal of the Transportation Research Board*, 2367(1), 53–59. https://doi.org/10.3141/2367-06

Zhang, Y., Wang, J., Wang, X., & Dolan, J. M. (2018). "Road-segmentation-based curb detection method for self-driving via a 3D-LiDAR sensor." *IEEE Transactions on Intelligent Transportation Systems*, 19(12), 3981–3991. https://doi.org/10.1109/tits.2018.2789462 Act Compliance Using 3-D Mobile LiDAR'

Zhao, G., & Yuan, J. (2012). "Curb detection and tracking using 3D-LIDAR Scanner." 2012 19th IEEE International Conference on Image Processing. https://doi.org/10.1109/icip.2012.6466890

APPENDIX A. ADA Compliance Checklists and Underlying Data

The following section presents the raw data collected using the Trimble TX8, iPhone LiDAR applications, and field measurements. LiDAR CAD application and 3D Scanner LiDAR application were the two LiDAR applications utilized to collect point cloud data on the iPhone 13 Pro. Finally, the two ADA compliance checklists for curb ramps and sidewalks were generated based on the 2010 ADA Standards for Accessible Design.

University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based 2010 ADA Standards for Accessible Design.)

	Yes	No
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)		
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)		
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)		
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)		
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)		
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)		
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)		
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)		
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)		
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)		
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)		

The following exceptions to the ADA curb ramp compliance checklist are noted from the 2010 ADA Standards for Accessible Design:
1. If there are space limitations for existing facilities, the curb ramps shall be no steeper than 1:8 with a maximum rise of three inches. (405.2)
2. If there is no landing at the top of a curb ramp, the curb flares shall be no steeper than 1:12 (406.4)

University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based 2010 ADA Standards for Accessible Design.)

	Yes	No
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)		
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)		
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)		
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)		
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)		
6. Is the cross slope no steeper than 1:48? (403.3)		
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)		
8. Is the route stable, firm, and slip-resistant? (302.1)		

The following exceptions to the ADA sidewalk compliance checklist are noted from the 2010 ADA Standards for Accessible Design:
1. Changes in level between 1/4 inch high and minimum and 1/2 inch high maximum shall be beveled with a slope not steeper than 1:2. (303.3).

iPhone LiDAR CAD Application Data Collection Summary

Scan Number	Block Face	Number of Points	Data (MB)
1	E. 28th Ave between Eudora St. and Elm St.	3,732,480	92.55
2	E. 28th Ave between Eudora St. and Elm St.	4,145,545	102.79
3	E. 29th Ave between Eudora St. and Elm St.	3,715,854	92.14
4	Elm St. between E. 28th Ave and E. 29th Ave.	7,156,873	177.46
5	Eudora St between E. 28th Ave and E. 29th Ave.	6,838,071	169.55
6	E. 29th Ave between Eudora St. and Elm St.	3,745,155	92.86
7	Elm St. between E. 28th Ave and E. 29th Ave.	7,081,202	175.58
8	Eudora St. between E. 28th Ave and E. 29th Ave.	6,839,668	169.59

Curb Ramp iPhone LiDAR CAD Application ADA Issues

	Scan 1 28th & Eudora	Scan 1 28th & Elm	Scan 2 28th & Eudora	Scan 2 28th & Elm	Scan 3 29th & Elm	Scan 4 29th & Elm	Scan 5 28th & Eudora	Scan 5 29th & Eudora	Scan 7 29th & Elm	Scan 7 28th & Elm	Scan 8 29th & Eudora	Total Non-Compliant
Check 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	2
Check 2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 3	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	0
Check 4	No	No	No	No		Yes		No	Yes	No	No	7
Check 5	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1
Check 6			No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	2
Check 7	N/A	No	N/A	No	No		N/A	N/A			N/A	3
Check 8	N/A	No	N/A	No	No		N/A	N/A	No		N/A	4
Check 9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0

Sidewalk iPhone LiDAR CAD Application ADA Issues

	Scan 1 28th Ave	Scan 2 28th Ave	Scan 3 29th Ave	Scan 4 Elm St	Scan 5 Eudora St	Scan 6 29th Ave	Scan 7 Elm St	Scan 8 Eudora St	Total Non-Compliant
Check 1	No	No	No	No	No	No	No	No	8
Check 2	Yes	Yes	Yes	No	No	Yes	No	No	4
Check 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Check 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Check 5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 6	No	No	No	No	No	No	No	No	8
Check 7	No	No	No	No	No	No	No	No	8
Check 8	Yes	Yes	Yes	Yes	No	Yes	Yes	No	2

LiDAR CAD Scan 1, 28th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.182/4.066 = 0.0447
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.025/4.163 = 0.006
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.164 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	.386/5.562 = 0.0693
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)		Scan 8 did not capture counter slope
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 1 did not capture all the features of 28th and Eudora curb ramp.

LiDAR CAD Scan 1, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.0497/3.194 = 0.015
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.022/4.519 = 0.004
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.837 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.045/5.004 = 0.008
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)		Scan did not capture counter slope of gutters.
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	Scan did not capture curbs on either side of curb ramp. There was not an existing marked crossing at this curb ramp location.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	The scan did not capture the bottom of the curb ramp. Based on the field visit, there does not appear to be 48 inch clear space outside of active traffic lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective opinion.

Note: Scan 1 did not capture all the features of the 28th and Elm Curb Ramp.

LiDAR CAD Scan 1, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.10 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.017/24.263 = .0007
6. Is the cross slope no steeper than 1:48? (403.3)	No	.197/1.918 = 0.102
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

LiDAR CAD Scan 2, 28th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.110/4.454 = 0.024
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.060/4.484 = 0.013
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.484 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.020/3.780 = 0.005
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.09/1.60 = 0.056
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

LiDAR CAD Scan 2, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.290/4.012 = 0.072
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.040/4.025 = 0.009
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.02 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	No	0.030/4.036 = 0.007
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.040/1.986 = 0.020
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb and gutter on either side of curb ramp. However, there is not a marked crossing at this location.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	Not captured in LiDAR Scan. Based on field visit, there was not a 48" clear space outside of vehicular traffic lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

LiDAR CAD Scan 2, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.57 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.17/11.572 = 0.014
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.22/1.950 = 0.112
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

LiDAR CAD Scan 3, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.2/4.284 = 0.046
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.050/3.489 = 0.014
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	3.489 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)		Did not capture enough point cloud data in scan to draw conclusion.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.070/5.928 = 0.011. Only captured curb ramp flare on 29th Ave.
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.120/2.372 = 0.050
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb and gutter on either side of curb ramp. However, there is not a marked crossing at this location.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	Not captured in LiDAR Scan. Based on field visit, there was not a 48" clear space outside of vehicular traffic lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 3 did not capture all of the features of the 29th and Elm Curb Ramp.

LiDAR CAD Scan 3, 29th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.78 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.040/25.715 = 0.001
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.06/2.393 = 0.025
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

LiDAR CAD Scan 4, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.280/3.720 = 0.075
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.020/3.645 = 0.005
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.633 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Yes, on the Elm Street side. Did not capture enough point cloud data in scan to draw conclusion on 29th Ave.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.327/6.824 = 0.047.
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.151/3.132 = 0.048
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)		There is 24" of curb and gutter on either side of curb ramp. However, there is not a marking crossing at this location.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)		Not captured in LiDAR Scan. Based on field visit, there was not a 48" clear space outside of vehicular traffic lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 4 did not capture all the features of the 29th and Elm Curb Ramp.

LiDAR CAD Scan 4, Elm St Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.71 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.861/41.790 = 0.020
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.304/2.455 = 0.123
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

LiDAR CAD Scan 5, 28th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.180/6.063 = 0.029
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.020/4.271 = 0.004
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)		Did not capture enough point cloud data in scan to draw conclusion.
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)		Did not capture enough point cloud data in scan to draw conclusion.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 5 did not capture all the features of the 28th and Eudora Curb Ramp.

LiDAR CAD Scan 5, 29th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	0.550/ 2.860 = 0.192
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.040/ 5.158 = 0.007
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.210/5.750 = 0.036
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.090/2.113 = 0.042
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

LiDAR CAD Scan 5, Eudora St Sidewalk

University of Colorado at Denver ADA Sidewalk Compliance Checklist

(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.987 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.040/21.666 = 0.001
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.24/2.247 = 0.106
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	Vertical change greater than 1/4" at grass and cobblestone.
8. Is the route stable, firm, and slip-resistant? (302.1)	No	There is not a continuous sidewalk. There are areas of grass and cobblestone.

LiDAR CAD Scan 6, 29th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.927 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.170/33.145 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.40/3.233 = 0.123
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective

LiDAR CAD Scan 7, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.300/6.881 = 0.043
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.010/4.468 = 0.002
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Yes. Could only verify Elm Street landing from data set.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.25/7.385 = 0.033
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.09/2.422 = 0.037
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)		Could not verify from point cloud data set.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	There is not a clear space outside of active travel lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 7 did not capture all of the features of the 29th and Elm Curb Ramp.

LiDAR CAD Scan 7, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.260/6.229 = 0.041
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.010/4.546 = 0.002
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	Could only verify Elm Street landing from data set.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.030/5.142 = 0.005. Could only verify Elm Street flare
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)		Could not verify from point cloud data set.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)		Could not verify from data set. Based on field visit, there is not a clear space outside of active travel lanes.
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

Note: Scan 7 did not capture all the features of the 28th and Elm Curb Ramp.

LiDAR CAD Scan 7, Elm St Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.966 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.230/17.084 = 0.013
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.330/1.884 = 0.175
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective

LiDAR CAD Scan 8, 29th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	0.580/2.798 = 0.207
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.020/4.737 = 0.004
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	4.737 feet
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.080/3.890 = 0.020
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.070/1.244 = 0.056
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective

LiDAR CAD Scan 8, Eudora St Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	2.943 feet
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.040/19.419 = 0.002
6. Is the cross slope no steeper than 1:48? (403.3)	No	0.28/2.419 = 0.115
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	No	There are areas with no sidewalk.

iPhone LiDAR 3D Scanner Application Data Collection Summary

Scan Number	Curb Ramp Location	Number of Points	Data (MB)
1	28th Ave and Eudora St	420,430	15.01
2	28th Ave and Eudora St	502,823	17.90
3	28th Ave and Elm St	447,187	15.91
4	28th Ave and Elm St	421,286	14.98
5	29th Ave and Elm St	686,742	24.38
6	29th Ave and Elm St	647,481	23.05
7	29th Ave and Eudora St	514,098	17.66
8	29th Ave and Eudora St	534,739	18.38

Curb Ramp 3D Scanner Application ADA Issues

	28th & Eudora West 1	28th & Eudora West 2	28th & Eudora South 1	28th & Eudora South 2	28th & Elm 3	28th & Elm 4	29th & Elm 5	29th & Elm 6	29th & Eudora 7	29th & Eudora 8	Total Non-Compliant
Check 1	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	3
Check 2	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	1
Check 3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 4	No	No	No	No	No	Yes	No	No	No	No	7
Check 5	N/A	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 6	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	No	3
Check 7	N/A	N/A	N/A	N/A	No	No	No	No	N/A	N/A	4
Check 8	N/A	N/A	N/A	N/A	No	No	No	No	N/A	N/A	4
Check 9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 11	N/A	N/A	N/A	N/A	N/A	N/A	Yes	Yes	N/A	N/A	0

3D Scanner LiDAR Scan 1, 28th and Eudora West Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.006/0.470 = 0.012
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.005/0.727 = 0.006
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.431 m x 3.28 ft/m = 4.69 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	N/A	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.021/0.457 = 0.045
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

3D Scanner LiDAR Scan 2, 28th and Eudora West Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.008/0.618 =0.012
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.002/0.572 = 0.003
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	N/A	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.035/0.509 = 0.068
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

3D Scanner LiDAR Scan 1, 28th and Eudora South Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.010/1.015 = 0.009
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.0001/0.8636 = 0.0001
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.3867 m x 3.28 ft/m = 4.54 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.104/1.466 = 0.070
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.019/0.435 = 0.043
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

3D Scanner LiDAR Scan 2, 28th and Eudora South Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.030/0.783 = 0.038
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	No	0.013/0.443 = 0.029
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.104/1/552 =0.067
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.037/0.405 = 0.091
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

3D Scanner LiDAR Scan 3, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.043/0.727 = 0.059
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.0008/0.6289 =0.0012
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.42 m x 3.28 ft/ m = 4.65 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	0.03/1.385 = 0.021
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.0001/0.4160 = 0.0002
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side. However, there is no marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

3D Scanner LiDAR Scan 4, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.038/0.688 = 0.055
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.005/0.903 = 0.005
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.013/0.458 = 0.028
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

3D Scanner LiDAR Scan 5, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	0.064/0.707 = 0.090
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.012/0.948 = 0.012
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.395 m x 3.28 ft/m = 4.57 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	0.034/1.539 = 0.022
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.019/0.752 = 0.025
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

3D Scanner LiDAR Scan 6, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	0.044/0.774 = 0.056
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.018/1.003 = 0.017
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	0.042/1.469 = 0.028
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.020/0.783 = 0.025
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

3D Scanner LiDAR Scan 7, 29th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	0.168/0.932 = 0.180
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.025/1.310 = 0.019
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.310 m x 3.28 ft/m = 4.29 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.030/0.431 = 0.069
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

3D Scanner LiDAR Scan 8, 29th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	0.170/0.872 = 0.194
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.014/1.418 = 0.009
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.41 m x 3.28 ft/m = 4.62 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	0.056/1.310 = 0.042
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	No	0.035/0.387 = 0.090
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

Trimble TX8 LiDAR Data Collection Summary

Scan Number	Location	Number of Points	Data (KB)
1	28th and Elm Curb Ramp, 65' of 28th, 73 ft of Elm	90,877,285	2,307,432
2	28th and Elm Curb Ramp, 82 ft of Elm	87,661,039	2,225,769
3	Elm Street near 28th Ave 100 ft Elm Street	94,630,771	1,848,258
4	Elm Street near 28th Ave 206 ft range	98,456,441	1,922,978
5	Elm Street- Midblock 100 ft range	92,365,286	1,804,010
6	Elm Street- near 28th Ave 190 ft range	78,385,335	1,530,964
7	Elm Street- Midblock 185 ft range	76,109,833	1,486,521
8	Elm Street- Midblock 148 ft range	69,295,427	1,353,427
9	Elm Street- Midblock 124 ft range	82,102,894	1,603,573
10	Elm Street- Midblock 149 ft range	95,849,209	1,872,056
11	Elm Street- Midblock 171 ft range	91,087,595	1,779,060
12	Elm Street- Midblock 136 ft range	98,227,601	1,918,509
13	Elm Street near 29th Ave	94,935,414	1,854,208
14	29th and Elm Curb Ramp	95,170,492	1,858,799
15	29th and Elm Curb Ramp	95,214,943	1,859,668
16	28th and Elm Curb Ramp	81,518,848	1,592,166
17	28th Ave	91,899,766	1,794,918
18	28th Ave	84,173,089	1,644,006
19	28th Ave Midblock 122 ft range	92,985,198	1,816,118
20	28th Ave Midblock 135 ft range	81,068,496	1,583,370
21	28th and Eudora Curb Ramp, 28th Ave Block Face	85,869,783	1,677,145

Curb Ramp Trimble TX8 LiDAR ADA Issues

	28th & Eudora South 1	28th & Elm 1	28th & Elm 2	29th & Elm 14	29th & Elm 15	28th & Elm 16	28th & Eudora South 21	Total Non-Compliant
Check 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 3		Yes	Yes	Yes	Yes	Yes	Yes	0
Check 4		No	Yes	Yes	Yes	Yes	No	2
Check 5		Yes	Yes	Yes	Yes	Yes	Yes	0
Check 6	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 7	N/A	No	No	No	No	No	N/A	5
Check 8	N/A	No	No	No	No	No	N/A	5
Check 9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 11	N/A	Yes	Yes	Yes	Yes	Yes	N/A	0

Sidewalk Trimble TX8 LiDAR ADA Issues

	28th Ave 1	Elm St 2	Elm St 3	Elm St 4	Elm St 5	Elm St 6	Elm St 7	Elm St 8	Elm St 9	Elm St 10	Elm St 11	Elm St 12	Elm St 13	28th Ave 17	28th Ave 19	28th Ave 20	28th Ave 21	Total Non-Compliant
Check 1	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	17
Check 2	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	12
Check 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Check 4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
Check 5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0
Check 6	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	17
Check 7	No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	13
Check 8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	0

Trimble TX8 Scan 1, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.90 m x 3.28 ft/m = 2.95 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.252 - 1.237 = 0.015 m Run = 5.69 m Rise/Run = 0.015/5.69 = 0.002
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.312 - 1.223 = 0.089 m Run = 0.87 m Rise/Run = 0.089/0.87 = 0.102
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	0.07 m x 3.28 ft/m = 0.22 ft
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 1, 28th and Eudora South Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.419 - 1.405 = 0.014 m Run = 0.86 m Rise/Run = 0.014/0.86 = 0.016
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.420 - 1.416 = 0.004 m Run = 1.09 m Rise/Run = 0.004/1.09 = 0.003
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)		Not enough data to draw conclusion.
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)		Not enough data to draw conclusion.
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)		Not enough data to draw conclusion.
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.422 - 1.393 = 0.029 m Run = 0.58 m Rise/Run = 0.029/0.58 = 0.05
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

Trimble TX8 Scan 1, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.393 -1.342 = 0.051 m Run = 0.91 m Rise/Run = 0.051 m/0.91 m = 0.05
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.364 - 1.342 = 0.022 m Run = 1.48 m Rise/Run = 0.022 m/1.48 m = 0.01
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.47 m x 3.28 ft/m = 4.82 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	Rise = 1.388 m - 1.317 m = 0.071 m Run = 1.20 m Rise/Run = 0.071 m/ 1.20 m = 0.05
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.376 m - 1.347 m = 0.029 Run = 0.69 m Rise/Run = 0.029 m/ 0.69 m = 0.04
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.394 m - 1.389 m = 0.005 m Run = 0.46 m Rise/Run = 0.005 m/ 0.46 m = 0.01
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side of curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

Trimble TX8 Scan 1, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.86 m x 3.28 ft/m = 2.82 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.337 - 0.202 = 1.175 m Run = 22.51 m Rise/Run = 1.175/22.51 = 0.05
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.461 - 1.409 = 0.052 m Run = 0.86 m Rise/Run = 0.052/0.86 = 0.06
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	Yes	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 2, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.372 -1.323 = 0.049 m Run = 0.85 m Rise/Run = 0.049 m/0.85 m = 0.05
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.351 - 1.335 = 0.016 m Run = 1.45 m Rise/Run = 0.016 m/1.45 m = 0.01
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.45 m x 3.28 ft/m = 4.75 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Rise = 1.324 m - 1.303 m = 0.021 m Run = 1.17 m Rise/Run = 0.021 m/ 1.17 m = 0.01
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.365 m - 1.333 m = 0.032 Run = 0.74 m Rise/Run = 0.032 m/ 0.74 m = 0.04
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.377 m - 1.376 m = 0.001 m Run = 0.67 m Rise/Run = 0.001 m/ 0.67 m = 0.001
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side of curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

Trimble TX8 Scan 2, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.77 m x 3.28 ft/m = 2.52 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.496 - 1.321 = 0.175 m Run = 25.56 m Rise/Run = 0.175/25.56 = 0.006
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.466 - 1.402 = 0.064 m Run = 0.77 m Rise/Run = 0.064/0.77 = 0.08
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	Dip in Sidewalk.
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 3, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.86 m x 3.28 ft/m = 2.82 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.326 - 1.189 = 0.137 m Run = 31.07 m Rise/Run = 0.137/31.07 = 0.004
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.321 - 1.278 = 0.043 m Run = 0.86 m Rise/Run = 0.043/0.86 = 0.05
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 4, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.81 m x 3.28 ft/m = 2.65 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.295 - 1.286 = 0.009 m Run = 8.66 m Rise/Run = 0.009/8.66 = 0.001
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.465 - 1.277 = 0.188 m Run = 0.95 m Rise/Run = 0.188/0.95 = 0.19
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 5, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.85 m x 3.28 ft/m = 2.78 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.363 - 1.185 = 0.178 m Run = 30.67 m Rise/Run = 0.178/30.67 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.409 - 1.293 = 0.116 m Run = 0.90 m Rise/Run = 0.116/0.90 = 0.12
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 6, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.85 m x 3.28 ft/m = 2.78 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.278 - 1.202 = 0.076 m Run = 11.16 m Rise/Run = 0.076/11.66 = 0.006
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.311 - 1.214 = 0.097 m Run = 0.67 m Rise/Run = 0.097/0.67 = 0.14
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 7, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.74 m x 3.28 ft/m = 2.42 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.381 - 1.308 = 0.073 m Run = 12.85 m Rise/Run = 0.073/12.85 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.359 - 1.303 = 0.056 m Run = 0.55 m Rise/Run = 0.056/0.55 = 0.10
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 8, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.63 m x 3.28 ft/m = 2.06 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.421 - 1.192 = 0.229 m Run = 45.33 m Rise/Run = 0.229/45.33 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.318 - 1.286 = 0.032 m Run = 0.63 m Rise/Run = 0.032/0.63 = 0.05
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 9, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.87 m x 3.28 ft/m = 2.85 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.407 - 1.194 = 0.213 m Run = 38.01 m Rise/Run = 0.213/38.01 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.381 - 1.313 = 0.068 m Run = 0.87 m Rise/Run = 0.068/0.87 = 0.07
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 10, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.86 m x 3.28 ft/m = 2.82 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.343 - 1.170 = 0.173 m Run = 45.73 m Rise/Run = 0.173/45.73 = 0.003
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.313 - 1.216 = 0.097 m Run = 0.86 m Rise/Run = 0.097/0.86 = 0.11
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 11, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.76 m x 3.28 ft/m = 2.49 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.288 - 1.257 = 0.031 m Run = 8.36 m Rise/Run = 0.031/8.36 = 0.003
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.414 - 1.327 = 0.087 m Run = 0.73 m Rise/Run = 0.087/0.73 = 0.11
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	Yes	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 12, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.59 m x 3.28 ft/m = 1.93 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.408 - 1.212 = 0.196 m Run = 41.54 m Rise/Run = 0.196/41.54 = 0.004
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.351 - 1.259= 0.092 m Run = 0.80 m Rise/Run = 0.092/0.80 = 0.115
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	Yes	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 13, Elm Street Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.79 m x 3.28 ft/m = 2.59 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.163 - 1.145 = 0.031 m Run = 6.59 m Rise/Run = 0.031/6.59 = 0.004
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.335 - 1.237 = 0.098 m Run = 0.82 m Rise/Run = 0.098/0.82 = 0.11
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	Yes	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 14, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.373 - 1.305 = 0.068 m Run = 1.06 m Rise/Run = 0.068 m/1.06 m = 0.06
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.343 - 1.340 = 0.003 m Run = 1.47 m Rise/Run = 0.003 m/1.47 m = 0.002
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.47 m x 3.28 ft/m = 4.82 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Rise = 1.301 m - 1.272 m = 0.029 m Run = 1.52 m Rise/Run = 0.029 m/ 1.52 m = 0.01
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.349 m - 1.281 m = 0.068 Run = 1.31 m Rise/Run = 0.068 m/ 1.31 m = 0.05
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.397 m - 1.376 m = 0.021 m Run = 0.57 m Rise/Run = 0.021 m/ 0.57 m = 0.03
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side of curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

Trimble TX8 Scan 15, 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.341 - 1.274 = 0.067 m Run = 1.13 m Rise/Run = 0.067 m/1.13 m = 0.05
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.309 - 1.307 = 0.002 m Run = 1.46 m Rise/Run = 0.002 m/1.46 m = 0.001
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.46 m x 3.28 ft/m = 4.78 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Rise = 1.244 m - 1.238 m = 0.006 m Run = 1.52 m Rise/Run = 0.006 m/ 1.52 m = 0.003
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.311 m - 1.262 m = 0.049 Run = 1.35 m Rise/Run = 0.049 m/ 1.35 m = 0.03
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.359 m - 1.343 m = 0.016 m Run = 0.49 m Rise/Run = 0.016 m/ 0.49 m = 0.03
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side of curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

Trimble TX8 Scan 16, 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.339 -1.290 = 0.049 m Run = 0.83 m Rise/Run = 0.049 m/0.83 m = 0.05
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.313 - 1.299 = 0.014 m Run = 1.44 m Rise/Run = 0.014 m/1.44 m = 0.009
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.44 m x 3.28 ft/m = 4.72 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	Rise = 1.287 m - 1.270 m = 0.017 m Run = 1.17 m Rise/Run = 0.017 m/ 1.17 m = 0.01
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.329 m - 1.295 m = 0.034 Run = 0.69 m Rise/Run = 0.034 m/ 0.69 m = 0.04
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.343 m - 1.339 m = 0.004 m Run = 0.61 m Rise/Run = 0.004 m/ 0.61 m = 0.006
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24" of curb on either side of curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	Subjective.

Trimble TX8 Scan 17, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.83 m x 3.28 ft/m = 2.72 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.228 - 1.204 = 0.024 m Run = 7.56 m Rise/Run = 0.024/7.56 = 0.003
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.238 - 1.176 = 0.062 m Run = 0.58 m Rise/Run = 0.062/0.58 = 0.10
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	Yes	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 18, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.56 m x 3.28 ft/m = 1.83 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.305 - 1.208 =0.097 m Run = 6.16 m Rise/Run = 0.097/6.16 = 0.015
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.246 - 1.186 = 0.06 m Run = 0.57 m Rise/Run = 0.06/0.57 = 0.10
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 19, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.67 m x 3.28 ft/m = 2.19 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.323 - 1.264 =0.059 m Run = 10.69 m Rise/Run = 0.059/10.69 = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.226 - 1.195 = 0.031 m Run = 0.67 m Rise/Run = 0.031/0.67 = 0.04
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 20, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.89 m x 3.28 ft/m = 2.91 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.268 - 1.238 =0.030 m Run = 12.89 m Rise/Run = 0.030/12.89 = 0.002
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.268 - 1.189 = 0.079 m Run = 0.89 m Rise/Run = 0.079/0.89 = 0.08
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Trimble TX8 Scan 21, 28th and Eudora South Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	Rise = 1.381 - 1.353 = 0.028 m Run = 1.54 m Rise/Run = 0.018
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	Rise = 1.373 - 1.369 = 0.004 m Run = 1.53 m Rise/Run = 0.004/1.53 = 0.002
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	1.53 m x 3.28 ft/m = 5.01 ft
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	Rise = 1.373 - 1.256 = 0.117 m Run = 1.68 m Rise/Run = 0.117/1.68 = 0.06
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	Rise = 1.374 - 1.352 = 0.022 m Run = 0.49 m Rise/Run = 0.022/0.49 = 0.04
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

Trimble TX8 Scan 21, 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	0.86 m x 3.28 ft/m = 2.82 ft
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	Rise = 1.251 - 1.206 = 0.045 m Run = 7.87 m Rise/Run = 0.005
6. Is the cross slope no steeper than 1:48? (403.3)	No	Rise = 1.282 - 1.195 = 0.087 m Run = 0.86 m Rise/Run = 0.087/0.86 = 0.10
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective.

Curb Ramp Field Measurements ADA Issues

	28th & Eudora West	28th & Eudora South	28th & Elm	29th & Elm	29th & Eudora	Total Non-Compliant
Check 1	Yes	Yes	Yes	Yes	No	1
Check 2	Yes	Yes	Yes	Yes	Yes	0
Check 3	Yes	Yes	Yes	Yes	Yes	0
Check 4	No	No	Yes	Yes	No	3
Check 5	N/A	Yes	Yes	Yes	Yes	0
Check 6	Yes	Yes	Yes	Yes	Yes	0
Check 7	N/A	N/A	N/A	No	N/A	1
Check 8	N/A	N/A	N/A	No	N/A	1
Check 9	Yes	Yes	Yes	Yes	Yes	0
Check 10	Yes	Yes	Yes	Yes	Yes	0
Check 11	Yes	Yes	Yes	Yes	N/A	0

Field Measurements 28th and Eudora West Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	1.9%
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.2%
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	N/A	
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	4.6%
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

Field Measurements 28th and Eudora South Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	1.4%
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.6%
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	4.6%
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	3.1%
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

Field Measurements 28th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	3.5%
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.5%
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	3.3% West Flare, 2.1% North Flare
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	0.6%
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is 24 inches of curb on either side of the curb ramp. However, there is not a marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

Field Measurements 29th and Elm Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	Yes	4.2%
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.4%
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	Yes	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	1.5% North Flare, 2.8% South Flare
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	1.2%
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	No	There is no marked crossing.
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	No	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	Yes	

Field Measurements 29th and Eudora Curb Ramp
University of Colorado at Denver ADA Curb Ramp Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the running slope of the curb ramp no steeper than 1:12, i.e. for every inch of height change there are at least 12 inches of curb ramp run? (406.1, 405.2)	No	11.4%
2. Is the cross slope of the curb ramp, excluding flares, no steeper than 1:48? (406.1, 405.3)	Yes	0.3%
3. Is the curb ramp, excluding flares, at least 36 inches wide? (406.1, 405.5)	Yes	
4. At the top of the curb ramp is there a level landing (slope no steeper than 1:48 in all directions) that is at least 36 inches long and at least as wide as the curb ramp? (406.4)	No	
5. If there are curb ramp flares, are the slopes of the flares no steeper than 1:10, i.e. for every inch of height change there are at least 10 inches of flare run? (406.3)	Yes	3.8% North Flare, 3.7% South Flare
6. Are the counter slope of the gutters adjacent to the roadway not steeper than 1:20? (406.2)	Yes	5.0%
7. For diagonal curb ramps with flared sides, is there a minimum of 24 inches of curb on either flared side of the curb ramps that are located within the marked crossing? (406.6)	N/A	
8. For diagonal curb ramps, does the landing at the bottom of the curb ramp have a minimum 48 inches length clear space outside active traffic lanes of the roadway? (406.6)	N/A	
9. If the accessible route crosses a curb, is there a curb ramp? (402.2)	Yes	
10. Are curb ramps and flared sides of curb ramps located outside of vehicular traffic lanes? (406.5)	Yes	
11. Are the landings for curb ramps designed to prevent the accumulation of water? (405.10)	N/A	

Sidewalk Field Measurements ADA Issues

	28th Ave	29th Ave	Eudora St	Elm St	Total Non-Compliant
Check 1	No	No	No	No	4
Check 2	Yes	Yes	No	No	2
Check 3	N/A	N/A	N/A	N/A	0
Check 4	N/A	N/A	N/A	N/A	0
Check 5	Yes	Yes	Yes	Yes	0
Check 6	No	No	No	No	4
Check 7	No	No	No	No	4
Check 8	Yes	Yes	No	Yes	1

Field Measurements 28th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.1%
6. Is the cross slope no steeper than 1:48? (403.3)	No	6.3%
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective

Field Measurements 29th Ave Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	Yes	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.3%
6. Is the cross slope no steeper than 1:48? (403.3)	No	5.6%
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective

Field Measurements Eudora St Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.9%
6. Is the cross slope no steeper than 1:48? (403.3)	No	4.6%
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	No	There are areas with no sidewalk.

Field Measurements Elm St Sidewalk
University of Colorado at Denver ADA Sidewalk Compliance Checklist
(Based on 2010 ADA Standards for Accessible Design.)

	Compliant	Notes
1. Is the route at least 36 inches wide? (Note: The accessible route can narrow to 32 inches minimum for a maximum of 24 inches. These narrower portions of the route must be at least 48 inches from each other. (403.5)	No	
2. If the route is greater than 200 feet in length and less than 60 inches wide, is there a passing space no less than 60 x 60 inches? (403.5)	No	
3. If there are grates or openings on the route, are the openings no larger than 1/2 inches? (302.3)	N/A	
4. Is the long dimension of the grate perpendicular to the dominant direction of travel? (302.3)	N/A	
5. Is the running slope no steeper than 1:20, i.e. for every inch of height change there are at least 20 inches of route run? (Note: If the running slope is steeper than 1:20, treat as such as edge protection and handrails.) (403.3)	Yes	0.2%
6. Is the cross slope no steeper than 1:48? (403.3)	No	6.0%
7. Is there a vertical change no greater than 1/4 inch in height? (303.2)	No	
8. Is the route stable, firm, and slip-resistant? (302.1)	Yes	Subjective